# EFFECTS OF TWO NEEM KERNEL EXTRACTS IN THE CONTROL OF WHITEFLY (*BEMISIA TABACI*) ON TOMATO

**BY:**

**Francis Appiagyei, B.Sc. (Hons.) General Agriculture**

KNUST

**A Thesis submitted to the Department of Theoretical and Applied Biology,**

**Kwame Nkrumah University of Science and Technology,**

**In partial fulfillment of the requirements for the degree**

**Of**

**MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE)**

**College of Science.**

**PG1814107**

NYANSAPƆ WƆSANE NO BADWENMA

**JUNE, 2010**

## DECLARATION

I hereby declare that this thesis is my own work towards the Master of Science degree (Environmental Science). And to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

**FRANCIS APPIAGYEI**

| | | |
|---|---|---|
| ………………………… | ……………………….. | …..………………… |
| Student (PG1814107) | Signature | Date |

Certified by:

DR. P. K. BAIDOO

| | | |
|---|---|---|
| ………………………… | ……………………….. | …..………………… |
| Supervisor | Signature | Date |

Certified by:

DR. P. K. BAIDOO

| | | |
|---|---|---|
| ………………………… | ……………………….. | …..………………… |
| Head of Department | Signature | Date |

## DEDICATION

I dedicate this work to God Almighty and to my supportive father, Mr. J.K. Nsafoah.

KNUST

## ACKNOWLEDGEMENT

My sincere gratitude goes to my sincere and dedicated supervisor Dr. P.K. Baidoo for his invaluable guidance, assistance and support towards the successful completion of this project. Special thanks also go to Dr. Ofori at the Faculty of Agricultural Engineering for his invaluable suggestions during the write up of this thesis. I am most grateful to Mr. Agyekum at the Meteorological Station, KNUST and finally to Mr. Adu-Bofour for the proof reading.

KNUST

# ABSTRACT

Whiteflies (*Bemisia tabaci* **Genn.**) are major insect pests of tomato plants in Ghana. The danger of these insect pests developing resistance to most synthetic insecticides has necessitated the need for alternative methods of controlling them. Neem products which are practically non-toxic and relatively harmless to man and beneficial insects are the best alternative against the control of these pests. Field trials were conducted in the minor rainy season of 2008 and major season of 2009 to assess the effectiveness of different neem-based products namely, aqueous neem kernel powder extract (ANKPE) and neem kernel powder extract (NKPE) against and *B. tabaci* and on the yield of tomato (*Lycopersicon esculentum* **Mill.**). Karate (Lambdacyhalothrin) was used as reference synthetic pesticide. The field design used was the Randomized Complete Block Design (RCBD) and there were four treatments with three replications. Data were collected on insect numbers, number of damaged leaves and the number of plants infected with tomato yellow leaf curl virus. The field trial was conducted on an experimental farm near the Sewage Treatment Plant at the Kwame Nkrumah University of Science and Technology, Kumasi in the Ashanti Region of Ghana. *B. tabaci* was detected on the tomato plants two weeks after transplanting in both seasons. The number of whiteflies was significantly lower ($F = 194.06$; $P < 0.0001$) in the neem - treated plants compared to the control plants but significantly higher than the karate - sprayed plants in the minor season. During the major season, the number of whiteflies on the karate - sprayed and neem - treated plants was significantly lower ($F = 96.38$; $P < 0.0001$) than the control plants. There was significant difference ($P < 0.001$) between ANKPE and NKPE in the minor season. However, there was no significant difference between the neem extracts in the major season. The number of damaged leaves on the control plants was significantly more ($F = 27.92$; $P < 0.0001$) than the karate - sprayed and neem - treated plants. The number of plants infected with tomato yellow leaf curl virus in the control was

significantly (F = 11.54; P < 0.0001) more than the karate and ANKPE - sprayed plants but did not differ significantly from NKPE. The number of plants infected with tomato yellow leaf curl virus (TYLCV) in NKPE did not differ significantly from ANKPE - sprayed plants in the minor season. No infection of tomato yellow leaf curl virus (TYLCV) was observed on all treatments during the major season. There was no significant difference (F = 3.11; P < 0.0887) in terms of yield among all the treatments in the minor season and in major season (F = 0.19; P < 0.897). Karate (Lambdacyhalothrin) did not prove superior to ANKPE and NKPE in the minor and major seasons. *B. tabaci* proved to be susceptible to the two neem extracts in the minor and major seasons. The neem extracts can therefore be used in the control of *B. tabaci*.

# TABLE OF CONTENTS

**Contents** **Page**

KNUST

## LIST OF FIGURES



KNUST

# LIST OF TABLES

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ANKPE | - | Aqueous Neem Kernel Powder Extract |
| ANOVA | - | Analysis of Variance |
| FAO | - | Food and Agriculture Organization |
| GTZ | - | German Development Cooperation |
| Kg | - | Kilogramme |
| KNUST | - | Kwame Nkrumah University of Science and Technology |
| NKPE | - | Neem Kernel Powder Extract |
| SAS | - | Statistical Analysis Systems |
| SNK | - | Student – Newman – Keuls test |
| TLV | - | Threshold limiting value |
| TYLCV | - | Tomato Yellow Leaf Curl Virus |

KNUST
NYANSAPɔ WɔSANE NO BADWENMA

# CHAPTER ONE

## INTRODUCTION

Tomato (*Lycopersicon esculentum* **Mill.**) is an important fruit vegetable in Ghana in terms of production and consumption. The popular commercial tomato variety grown is "Power" which is mainly grown in southern Ghana. The crop is grown mainly for the market and it is a good source of vitamins A, B and C. It is also an important source of income to both producers and retailers in Ghana. Demand for tomato in Ghana is high and therefore production is all year round: under rain-fed conditions in the wet seasons and under irrigation in the dry seasons (Bonsu, 2002). However, yield values are low. The average yield for the country stood at 5.4 metric tons per hectare as against an average of 20.13 metric tons per hectare for the African continent (Bonsu, 2002). He attributed the low yield to diseases, insect-pests and other environmental factors such as temperature and humidity.

Tomato plants are subject to infestation by insect pests such as, the whitefly (*Bemisia tabaci*), cotton aphid (*Aphis gossypii*), and the Leaf miner (*Liriomyza trifolii).* Aphids prefer to attack the tender shoots and the young leaves of the host plant, but they can also exist on older leaves. Apart from removing plant nutrients, the whitefly transmits a number of viral diseases such as Tomato Yellow Leaf Curl Virus (TYLCV), a disease that severely affects crop yields (Horna, *et al*., 2008). Tomato Yellow Leaf Curl Virus (TYLCV) is one of the major constraints to tomato cultivation in Ghana (Horna, *et al*., 2008). As a result of the devastating effects of the application of synthetic chemical insecticides such as acute and chronic poisoning of farm workers and consumers; groundwater contamination and the emergence of resistance to insecticides in insect-pest populations, attention is now being paid to the use of biopesticides such as neem extract. The biological activities of the most active ingredient limonoid azadirachtin include feeding and oviposition deterrence, repellency, growth disruption, reduced fitness and sterility (Saxena, 1989; Isman and Port, 1990; Koul and

Isman, 1991; Schmutterer, 1990). The leaves and seeds are both used effectively, but the chemical is concentrated in the fruit, especially in the seeds. Good results in insect control have been obtained with azadirachtin containing seed extracts under field conditions (Ahmed, 2000).

## 1.1 STATEMENT OF THE PROBLEM

Vegetables in tropical countries are often seriously attacked by insect-pests. Because of high susceptibility of tomato plants to insect pests, farmers tend to apply chemicals for protective purposes. In order to support tomato cultivation in Ghana, it is important to develop alternative methods of pest control. Neem products, which are practically non-toxic to man and warm-blooded animals and relatively harmless to beneficial insects (Ogemah, 2003), can be suitable for the control of insect pests in tomato cultivation. Even though the application of neem kernel extracts has proved effective against okra and cotton in Sudan (Ahmed, 2000), there is little evidence of its effects on tomato cultivation in Ghana. Also the lack of standardization of neem products in the country has contributed to its low patronage in the control of insect pests. Therefore field experiments need to be carried out in Ghana to ascertain the effectiveness of neem products in controlling whiteflies on tomato plants in Ghana.

## 1.2 JUSTIFICATION OF THE STUDY

Many workers are now concentrating their research on the effects of neem on vegetables. This is mainly due to the relatively harmless effects of neem products to beneficial insects. The conventional technology in the use of synthetic insecticides has not been very effective against numerous homopterans because they generally feed on the underside of foliage or within the plant canopy. Their small size, short life cycle, short generation time, and high fecundity result in high reproductive rates. These permit dramatic changes in population sizes and rapid differentiation of populations into insecticide-resistant strains, necessitating increased control actions. Good results have been obtained in the use of neem kernel seed extract on garden eggs (Owusu-Ansah, *et al*., 2001) and on cabbage (Obeng-Ofori and Ankrah, 2002). Various formulations of neem insecticides have been developed and are in use especially in India and Pakistan (Panhwar, 2005). Ghana can therefore not be left out in the development of suitable neem products in the control of insect pests.

### 1.3 GENERAL OBJECTIVE

The main objective of this project is to assess the effect of two neem kernel extracts namely: Aqueous Neem Kernel Powder Extract (ANKPE) and Neem Kernel Powder Extract (NKPE) in the control of whitefly (*Bemisia tabaci*) on tomato.

### 1.4 SPECIFIC OBJECTIVES

The specific objectives are to:

1. Determine the effect of the application of Aqueous Neem Kernel Powder Extract (ANKPE) in the control of whitefly (*B. tabaci*) on tomato.
2. Determine the effect of Neem Kernel Powder Extract (NKPE) in the control of white fly (*B. tabaci*) on tomato.
3. Compare the effect of the applications of neem extracts to that of Karate (Lambdacyhalothrin) in the control of whitefly (*B. tabaci*) on tomato.
4. Compare the yields of neem – treated plants to that of Karate (Lambdacyhalothrin).

## 1.5 RESEARCH QUESTIONS

In the light of the specific objectives stated in section 1.4, the following research questions were considered:

- What effect does neem extracts have on other insect pests of tomato?
- What is the mode of action of neem extracts on whiteflies?
- How effectively can neem extracts control the number of whiteflies, reduce leave damage and consequently the number of plants infected with tomato yellow leaf curl virus?
- Would the neem extracts be effective in controlling whiteflies as compared to karate?
- Would the application of the neem extracts increase tomato yield when compared to karate?

KNUST

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 VEGETABLE PRODUCTION IN GHANA

Vegetables are important component in the human diet because they supply nutrients such as vitamins C, A as well as appreciable quantities of the various B vitamins and minerals which are often lacking in most traditional staple foods. Vegetables also provide ‘roughage’ in the form of cellulose which aids in the digestion of other foods (Peet, 1995).

KNUST

## 2.2 TOMATO (*LYCOPERSICON ESCULENTUM* MILL.)

Tomato (Solanaceae) originated in tropical Central and South America especially Ecuador and Peru (George, 1985). The tomato plant is a late comer to Africa. It appears that it was not cultivated in Africa until the end of the 19$^{th}$ century. However, it is now an important component in the diet of West Africans. It is usually eaten in fairly large amounts as flavouring in stews and soups, and in the raw state in pepper sauces and occasionally in salads (Tweneboah, 1998). Tomatoes are a popular food item in Ghana. As main sources of vitamins A and C, they are consumed on a daily basis in many households. Moreover, tomato production is an important source of income for smallholder farmers. While domestic tomato production has intensified across the country in recent years, it still does not meet the high demand, so tomatoes are imported from Burkina Faso five to six months of the year (Horna, *et al.*, 2006). However, there is now increasing quantities being processed by factories into secondary products such as tomato paste. Tomato production can be very rewarding to the gardener, given reasonably fair treatment.

## 2.3 CONSTRAINTS TO TOMATO PRODUCTION IN GHANA

Several factors affect the cultivation of tomato in Ghana. One of the several factors is the acquisition of quality seeds for propagation. According to Horna, *et al.* (2006), farmers obtain seeds either from their own fields, from neighbours and friends, or from women's groups that maintain and distribute varieties that are in high demand in the marketplace. This recycling drives down seed price, but has a negative effect on seed quality. Most tomato varieties used in commercial production are exotic varieties, which are not well adapted to local conditions in Ghana (Bonsu, 2002). This, together with the seasonality of tomato production, creates periods of abundance and scarcity, which dramatically affect market prices (Horna, *et al.,* 2006). On the average, labour (land preparation, transplanting and harvesting) accounts for more than 50% of total production costs, but farmers who use family labour are hardly aware of this (Horna, *et al.,* 2008; Bonsu, 2002). Services and equipment costs together account for only 6% of the total expenses incurred by a tomato farmer (Horna, *et al.,* 2008). Manure is often used as fertilizer by producers across the region. During the rainy season, fungal diseases and pests are common. Synthetic insecticides and fungicides are generally too expensive for the average farmer to use. In addition, access to irrigation facilities is a problem. Despite these constraints, farmers consider tomato production to be a profitable activity (Horna, *et al.*, 2008).

## 2.4 BOTANY OF THE TOMATO PLANT

Tomato belongs to the family Solanaceae. They are typically long – day annuals or short – lived perennials cultivated as annuals. Different cultivars have different growth habits but they may be divided into two main groups as follows:

- Erect, dwarfs or bush types with fairly thick, solid, determinate (inflorescence or shoot with primary axis terminated early with a flower bud) stems which sprout numerous branches. The erect or dwarf tomatoes grow as a small bush. As a result, staking is usually not required and secondary stems need not be removed. For production of quality fruits, some of the numerous side shoots have to be removed. It is also easier to grow, but the fruits are produced near the ground and may rot if they come into contact with soil or mulch, especially in high rainfall areas (Obeng-Ofori, *et al.*, 2007).

- Tall, trailing or semi-climbing types with weak, thinner indeterminate (growth of stem, branch or shoot not limited or stopped by development of a terminal bud) stems which normally require support in the form of stakes to produce a good crop. To obtain bigger quality fruits, the plants are pruned by cutting off the growing point and are then staked.

Vegetative growth of the tomato plant occurs by the development of a bud in the axil of a leaf just below the apex while the inflorescences develop from the apical bud. Self – fertilization is usually the rule; the subsequent fruit is a berry with a smooth, soft skin. Tweneboah (1998) has observed that there are considerable variations in cultivars in the size and shape of the fruit, the percentage of soluble solid content, and factors such as colouration of the fruits and their degree of seediness and acidity. The characteristic red and yellowish colours of the fruits are due to various combinations of carotene and lycopersicin (lycopene) in the fruits.

**2.5 VARIETIES OF TOMATO**

All local cultivars are of the erect type but a number of imported trailing types are in cultivation in backyard and market gardens (Obeng-Ofori, *et al.*, 2007). Several varieties have been introduced and tried in Ghana with varying degrees of success. The most popular of these varieties available on the market appear to be 'Improved Zuarungu' a local selection recommended for dry – season gardening in the North (Tweneboah, 1998) and 'Power' which is popular in the southern part of Ghana (Bonsu, 2002). The local varieties produce large, ridged fruits with thin skin which split and bruise easily. The fruits contain more seeds. Yields are relatively higher under favourable conditions such as adequate moisture, disease-free conditions, weed control and judicious fertilization. Yields of 30-50 tonnes per hectare have been recorded on farms in the Dawhenya and Sege areas (Tweneboah, 1998). Some exotic varieties include Marglobe, Marvel, Money-maker, Roma and Fireball. The exotic varieties are generally not suitable for large scale cultivation under traditional systems of management, especially in the more humid areas of the forest zone. They are mainly grown for the canning industries or for foreign market (Tweneboah, 1998).

## 2.6 AREAS OF PRODUCTION

Tweneboah (1998) has recognized the following areas for the production of tomatoes on commercial scale in Ghana mainly as a monocrop:

- A belt extending from Ashaiman and Dawhenya to Sege and Ada in the Greater Accra Region.
- The Mankesim-Agona- Swedru – Nsawam areas in the Central and Eastern Regions.
- Ohawu-Keta areas in the Volta Region.
- Wenchi-Kintampo areas in the Brong –Ahafo region and Ofinso (Akomadan) and Mampong areas in the Ashanti Region.
- Dry season gardening in the North and the two Upper Regions especially in Navrongo, Frafra and Kusasi areas.

## 2.7 NURSERY MANAGEMENT

### 2.7.1 Seedbed preparation

For good drainage the seedbed should be raised to about 0.3-0.5 metres high. It should be well-forked and raked to remove stones and roots until the top is even. The soil may be mixed with well-rotted farm yard manure or poultry droppings and settled by watering. N.P.K 15-15-15 may be added with advantage. The nursery bed must be kept free of weeds at all times (Tweneboah, 1998; Bonsu, 2002).

### 2.7.2 Methods of sowing

The seeds are sown thinly in rows 10 – 15 cm apart in the seedbeds and about 2.5 cm deep. Germination takes 3-5 days and when the seedlings are 5 cm high; they are thinned or pricked-out onto a prick-out bed to a distance of about 5-6 cm apart (Tweneboah, 1998; Bonsu, 2002). The young seedlings must be protected when necessary from severe sunlight.

### 2.7.3 Nursery activities

The nursery beds must be watered regularly until the seedlings are transplanted. The seedlings must also be protected from diseases such as dumping off, a common seedbed disease and other diseases such as leaf mould, by promptly spraying with the appropriate fungicide. African mole cricket, ants and caterpillars are controlled by spraying with an appropriate insecticide (Obeng-Ofori, *et al.*, 2007).

### 2.7.4 Transplanting

After 2-6 weeks when the seedlings are 15-30 cm high and the stems are of pencil size, they are transplanted from the prick-out beds to their permanent beds (Obeng-Ofori, *et al.*, 2007). Transplanting can be done early in the morning or late in the evening, preferably when the soil is moist so that the roots will not be damaged.

#### 2.7.4.1 Methods of transplanting

Before transplanting the nursery beds should be watered. The seedlings are drawn from the nursery beds with a ball of soil around the root. Only healthy and vigorous seedlings should be planted out. After transplanting the seedlings should be pressed in firmly and watered as soon as possible (Bonsu, 2002).

#### 2.7.4.2 Planting distance

Various planting distances have been recommended. 60cm x 30cm - 60cm x 60cm, and 75cm x 75cm - 60cm x 40 cm (Tweneboah, 1998; Obeng-Ofori, *et al.*, 2007).

#### 2.7.4.3 Time of planting

Transplanting can be at any time of the year, with preference for drier periods of the year when diseases are less of a menace and consumer demand is high. For rain fed production in the forest zone, transplanting is done in March-April and August –November. In the Guinea and Sudan savanna zones of the North of Ghana, transplanting is usually done in October-November (dry season gardening) and in April whilst on the Accra plains, transplanting normally take place in September-October (Tweneboah, 1998; Obeng-Ofori, *et al.,* 2007).

KNUST

## 2.8 ECOLOGICAL REQUIREMENTS

### 2.8.1 Soils

Fertile, well-drained sandy loams to loamy soils are regarded as the most suitable for profitable cultivation of tomatoes. The tomato plant has a fine, shallow root system and provided drainage is good, the depth of soil beyond 40 cm is of minor importance. The pH of the soil may vary from pH 5.0 – 7.5 (Tweneboah, 1998; Obeng-Ofori, *et al.*, 2007).

### 2.8.2 Climate

Tomatoes are adapted to a wide range of climatic conditions and provided the varieties are carefully chosen, they can grow under most climatic conditions in Ghana. However, the heavy rainfall and humid conditions of the forest zone are not considered ideal for large-scale commercial production of the crop due to high incidence of diseases such early blight, leaf mould and leaf spot (Obeng-Ofori, *et al.,* 2007). In most parts of Ghana, the best results are obtained in the dry season with supplementary water. The high temperatures accompanied by cool nights in the North during the dry season favours good fruit setting and high yields (Tweneboa, 1998). Generally the best results in terms of yields and quality are obtained in drier, less humid areas of the interior and to a lesser extent, coastal savanna zones particularly during the dry season and under irrigation (Bonsu, 2002).

### 2.8.3 Fertilization

Phosphorus is essential during the early growth of the plants and for early maturity. A well balanced nitrogen / potassium ratio is also important for good growth and quality of the fruits. The nitrogen requirements of tomatoes are especially high after the setting of the first fruits, and top-dressing with nitrogen at this stage is therefore essential (Peet, 1995). However, excess nitrogen is associated with excessive vegetative growth at the expense of fruit formation, puffiness of the fruits and high incidence off blossom-end rot. On the Accra plains for example, farmers are often advised to apply 5-6 bags of 15-15-15 NPK per hectare. The benefits of fertilizer use in terms of increased yields and fruit size are appreciated, but because of lack of ready and stable market with favourable prices during peak season, few farmers follow the above recommendations (Tweneboah, 1998).

### 2.8.4 Pruning

The number of fruiting branches may be limited by pruning, so that the nutrients used in forming new leaves are diverted to form more and bigger fruits. Pruning, especially removal of axillary shoots, is recommended for staked plants, for it increases fruit quality. However, there is slight decrease in total yield of fruits (Obeng-Ofori, *et al.*, 2007).

### 2.8.5 Watering

Watering is done by using watering cans in backyard farming and by overhead or furrow irrigation in commercial large-scale market gardens. Until fruiting, the tomato crop has a high water requirement throughout the growing period, and watering may be regular, especially during dry periods (Bonsu, 2002).

### 2.8.6 Maturity and harvesting

The crop requires a growing period of 10-12 weeks. The harvest period continues for 8-10 weeks. Tomatoes are harvested ripe (in red colour) for the local market (Tweneboah, 1998; Ahmed, 2000).

## 2.9 COMMON DISEASES AND INSECT PESTS OF TOMATO

### 2.9.1 Diseases

Tomato plants are subject to infestation by Tomato Yellow Leaf Curl Virus (TYLCV), leaf spot, late blight (*Phytophthora infestans*), bacterial leaf spot (*Xanthomonas vesicatora*), Blossom End Rot (caused by water stress) and nematodes (Tweneboah, 1998; Ahmed, 2000).

#### 2.9.1.1 Tomato yellow leaf curl virus (TYLCV)

The most diagnostic symptoms appear in the leaves. Infected leaves remain small, curl upward, appear wrinkled, and interveinal and marginal yellowing or chlorosis occur. Early stage infected plants show severe stunting, whilst infestation during later stages of growth show stunting followed by an erect plant growth. Infected plants have shorter internodes and an overall bushy appearance (Brown, *et al*., 1995; Gilbertson, 2008).

### 2.9.2 Insect pests

Tomato plants are subject to infestation by the sucking insects, whitefly (*B. tabaci*) and cotton aphid (*A. gossypii*). African mole cricket (*Gryllotalpa africana*) cuts newly transplanted seedlings. African bollworm (*Helicoverpa armigera*) attacks the ripped and pre-ripped fruits  and exposing them to fungi and bacteria. Leaf miner (*Liriomyza trifolii)* also attacks tomato leaves causing various losses (Bonsu, 2002; Ahmed, 2000).

## 2.10 TOBACCO WHITEFLY (BEMISIA TABACI) (GENN.) (HOMOPTERA: ALEYRODIDAE)

### 2.10.1 Distribution and host plants

Whitefly, *Bemisia tabaci*, is one of the most serious insect pests of vegetables in the world. Their populations increase with temperature and decrease with rainfall within a month. Peak whitefly populations usually occur in the hot dry seasons. Whiteflies have a wide host range and are capable of feeding on over 500 plant species from 74 families (Martin, 1999; Perring, 2001).

### 2.10.2 Biology and ecology of whiteflies

According to Schmutterer (1969), whiteflies are known to reproduce bisexually or parthenogenetically, and hence numerous generations can occur during the year. Both adults and nymphs suck the plant sap.

Eggs are tiny (about 0.2 mm long) and pear-shaped. They stand upright on the leaves, being anchored at the broad end by a short stalk inserted into the leaf. They are laid usually in arcs or circles, on the undersides of young leaves. Eggs are whitish in colour when first laid, but gradually turn brown. Some whiteflies deposit large quantities of wax around the eggs in the form of a loose spiral like a fingerprint. Hatching occurs after 5-10 days at 30°C depending on species, temperature and humidity (Martin, 1999).

On hatching, the first instar nymph is flat, oval and scale-like, and greenish-white in colour. It is the only mobile nymphal stage. It moves to a suitable feeding location on the lower leaf surface where it settles. It moults, losing the legs and antennae, and can not move throughout the remaining immature stages. The first three nymphal stages last 2-4 days. Many species produce large quantities of waxy secretions around the margins and the dorsal surface of the nymph (Martin, 1999). The total nymphal period lasts 2-4 weeks depending on temperature. Large populations may develop within three weeks under optimum conditions, and the lower leaf surfaces may be almost covered by immature stages. The adult usually emerges through a T-shaped split in the dorsal surface of the nymphal case. They are usually found on mature leaves (Legg, *et al.*, 2003).

Adults are small (1-3 mm long), with two pairs of wings that are held roof-like over the body. They resemble very small moths. Their body is pale yellow. The body and wings are covered with a powdery, waxy coating. Whiteflies are mostly white, but can also be yellowish and some species have dark or mottled wings (Perring, 2001). They have sucking mouthparts. They are often found clustered in groups on the underside of young leaves and readily fly away when disturbed. A female may live for 60 days; life of the male is generally much shorter (9 to 17 days) (Martin, 1999; Legg, *et al.*, 2003). Whiteflies adults do not fly very efficiently but, can be transported long distances by the wind. All stages of the pest are liable to be carried on plant materials (Legg, *et al.*, 2003).

**2.10.3 Major species of whiteflies**

Some of the major species of whiteflies identified by Legg, *et al*. (2003) in Africa include:

- The cabbage whitefly (*Aleyrodes proletella*)
- The greenhouse whitefly (*Trialeurodes vaporariorum*)
- The tobacco whitefly or sweet potato whitefly (*Bemisia tabaci*)
- The spiralling whitefly (*Aleurodicus dispersus*)
- The citrus wolly whitefly (*Aleurothrixus floccosus*)

**2.10.4 Damage**

Whiteflies cause direct damage to plants by sucking plant sap and removing plant nutrients, thereby weakening the plants (Perring, 2001; Martin, 1999). Damage may be more severe when plants are under water stress. In addition, they often produce large quantities of honeydew that leads to the growth of sooty mould on the lower leaves, blocking or reducing the photosynthetic capacity of the plants (Brown, *et al*., 1995). The honeydew also contaminates the marketable part of the plant, reducing its market value or making it outright sale difficult. Infested plants may wilt; turn yellow in colour, become stunted or die when whitefly infestations are severe or of long duration (Martin, 1999). Whiteflies are also serious indirect pests as vectors of virus diseases. *Bemisia tabaci* transmits viral diseases on cassava, cotton, tobacco, tomato, beans, chillies, and sweet potatoes (Brown, e*t al*., 1995). Whitefly transmitted viruses are among the most serious viral diseases on plants, often resulting in total crop losses. Whitefly is the vector of a range of leaf curl disease-inducing virus, in Eastern and Southern Africa, including the Tomato Yellow Leaf Curl Virus, the cassava mosaic virus, the cowpea mild mottle virus, the watermelon chlorotic stunt virus among others (Legg, *et al*., 2003).

#### 2.10.5 Symptoms of whitefly infestation

The feeding of whiteflies causes yellowing of infested leaves. Whiteflies excrete honeydew, a clear, sugary liquid which covers the lower leaves and supports the growth of black sooty mould, which may coat the entire plant (Gilbertson, 2008). Where plant viruses are transmitted, plants show the typical symptoms of the virus diseases. Presence of whiteflies can also be recognized by a cloud of tiny whiteflies flying up when the plants are shaken. The whiteflies resettle soon on the plants. Affected plant stages are the seedling, vegetative growing stage and flowering stage. Affected plant parts are mainly the leaves (Legg, *et al*., 2003).

#### 2.10.6 Control of whiteflies

##### 2.10.6.1 Cultural control

Clean-up measures such as removal of weeds and alternative hosts (Schmutterer, 1969), reducing the frequency of irrigation and modifications of the spacing of plant populations have been reported to reduce the population build-up of whiteflies (Sharafel, 1986).

### 2.10.6.2 Biological pest control

Whiteflies are attacked by a large number of natural enemies such as parasitic wasps (e.g. *Eretmocerus* spp., *Encarsia* spp.), predatory mites (*Amblyseius* spp. and *Typhlodromus* spp.), predatory thrips, lacewings, rove beetles and ladybird beetles. The dusty lacewing (*Conwentzia africana*) is considered to be one of the most important predators of *B. tabaci* in East and Southern Africa (Legg, *et al*., 2003).

## 2.11 INSECTICIDES

KNUST

### 2.11.1 Classification of insecticides

When classified by mode of action, insecticides are referred to as stomach poisons (those that must be ingested), contact poisons, or fumigants. The most precise method of classifying insecticides is by their active ingredient (toxic component) (FAO, 2000). According to this method the major classes of insecticides are:

- chlorinated hydrocarbons
- organophosphates
- carbamates
- pyrethroids.

Other categories in this classification system include the biologicals (or microbials), botanicals, oils, and fumigants (FAO, 2000). Very often, pesticides are grouped into systemic or non-systemic products. Systemic pesticides are taken up by plants through the roots, stems or leaves. Once inside the plant, they move through the plant's vascular system to other untreated parts of the plant (Encyclopaedia Britannica, 2010). Non-systemic pesticides are not taken up by the plant, and simply form a layer on the sprayed insects or on plant parts. Systemic pesticides can be effective against pests that live inside the plant, where ordinary non-systemic pesticides cannot reach them (FAO, 2000). Examples of such pests include sucking insect-pest protected inside buds, borers inside stems, and nematodes inside roots. Before using a systemic pesticide, it is important to check its persistence.

#### 2.11.2 Effects of synthetic insecticides on insects and natural enemies

##### 2.11.2.1 Development of resistance

The development of resistance is one of the more serious problems in pest management. Resistance means that an insect, disease, or weed becomes able to tolerate a pesticide that is used to kill it (FAO, 2000). Many insect pest species have now developed resistance to some types of insecticides, and few chemical control options exist for these pests (Tetteh and Glover, 2008). The number one resistant insect is the aphid, *Myzus persicae* (Homoptera: Aphidae). Aphid is resistant to more insecticides than any other insect. Some plant diseases and weeds have also developed resistance to certain fungicides and herbicides (FAO, 2000).

##### 2.11.2.2 Resurgence of pest populations

A well-known phenomenon is that when natural enemies are killed by pesticide applications, insect pests which often have a high reproduction rate can increase their numbers very quickly. Pesticides reduce the number of pests, but then the pests "spring back" and may even be worse than before (FAO, 2000). This is especially true for pests that have developed some resistance against pesticides. The reason is, when sprayed, most of the natural enemies are killed by the insecticide. But some pests always survive an insecticide spray, and keep on reproducing. With no natural enemies to kill them, the pests will increase in number within a short time. Another problem is that, after spraying to control one pest, a second type of pest will suddenly start to damage the crop since most its natural enemies are killed by the insecticide. This will allow the second pest to reproduce very quickly. A well-known example is red spider mite. When no insecticides are used, red spider mite is often controlled by its natural enemies. But, red spider mite can cause severe problems in heavily sprayed fields (FAO, 2000). Another example in tea is caterpillars, which can become more abundant after the field is sprayed to control other pests. Natural enemies are often hurt more by chemical insecticides than the target pest. Because predators and parasitoids must search for their prey, they generally are very mobile and spend a considerable amount of time moving across plant. This increases the likelihood that they will get in contact with the pesticide. Also, they may feed on or live inside poisoned prey. In addition to killing natural enemies immediately, pesticides may also have sub lethal effects on insect behavior, reproductive capabilities, egg hatch, rate of development, feeding rate, and life span (FAO, 2000)

#### 2.11.2.3 Negative impacts on animals within and outside the crop system

There are numerous cases of negative impact of pesticides on livestock. For example, pesticides sprayed, can be blown onto livestock by wind or livestock can accidentally be fed plants that have been sprayed. Wild animals that live near agricultural fields may also be affected (Isman, 2006).

## 2.12 BOTANICAL PESTICIDES

Some plants contain chemicals that are toxic to insects. When extracted from plants, these chemicals are called Botanicals (Weaver and Sumbramanyam, 2000). Generally, botanicals break down more rapidly than most conventional pesticides. Therefore, they are considered relatively environmentally safe and less likely to kill natural enemies than insecticides with longer residual activity. Toxicity to other organisms is variable. As a group, botanicals tend to be less toxic to mammals than non-botanicals (Weaver and Sumbramanyam, 2000). Because they generally degrade within a few days or hours after being applied, botanicals must be applied more often than conventional pesticides (Hydra, 1998). Another disadvantage is that, if farmers must purchase botanicals from a commercial producer, they are usually more expensive than synthetic insecticides. But when they can be produced within the village or by the farmer herself or himself, they may be cheaper to use than synthetic insecticides (Childs, *et al*., 2001).

## 2.13 NEEM TREE (AZADIRACHTA INDICA A. JUSS)

Neem belongs to the order Rutales and the family Meliaceae (Panhwar, 2005). It has many common names which are region specific and have various meanings in respective regions. In Ghana, neem tree is called “King”, which is the local title for governor.

### 2.13.1 Geographic distribution of neem in Ghana

Neem is thought to have originated in India and Myanmar where it is common throughout the central dry zone and the Siwalik Hills, although the exact origin is uncertain (National Research Council, 1992). The neem tree is now widely distributed by introduction into tropical and subtropical zones of Asia, America, Australia, South Pacific Islands and Africa. According to Childs *et al.* (2001), the cultivation of neem spread to Africa in the 1920’s when it was introduced to Ghana, Nigeria and the Sudan, and the species is now well established in more than 30 countries.

## 2.14 INTRODUCTION AND DISTRIBUTION OF NEEM IN GHANA

In Ghana, neem has been growing on the plains near Accra, since the 1920s. The trees have naturalized, and their spread has been boosted by birds and bats that feed on the fruits and spit out the seeds while sitting on the branches. Neem is now scattered all over the area. There are now millions of neem trees growing in Ghana, especially in the coastal and interior savannahs (Schmutterer, 1998). Many of these trees are used for the production of firewood and charcoal, but other potential uses remain under-exploited. In recent years, there has been interest in neem in Ghana for crop protection, both in the field and storage. The German Development Cooperation (GTZ), through the Goethe Institute in Accra, has held two conferences, the first in 1998 on ‘The potential of the neem tree in Ghana’ and the second in 1999 on ‘Commercialization of neem in Ghana’ (Childs, *et al*., 2001). These conferences have succeeded in promoting awareness of neem to a number of institutions within Ghana and have also helped to network the activities of these institutions. As a result of the conference in 1998, three working groups were set up within Ghana: ‘Neem as a pesticide,’ ‘Neem as a cosmetic’ and ‘Neem for afforestation’ (Childs, *et al*., 2001).

The results of farmers’ survey conducted by Childs *et al.* (2001), suggested that the most common use of neem in Ghana is for medicinal purposes, with 60-80% of farmers in all agro-ecological zones reporting that they used neem for this purpose. In general, the use of neem for other purposes was not common, but the use of neem was greater in both the coastal and interior savannah, where there are more neem trees, than in the forest zone. Nineteen percent (19%) of farmers indicated that they used neem for crop protection, with 9% of farmers indicating that they used neem to protect their stored crops whilst 12% of farmers indicating that they used neem to protect their crops in the field. According to Childs *et al.* (2001), these figures were higher than was expected, but closer examination of the data revealed that the use of neem for crop protection was strongly linked to areas where there had been recent interventions promoting neem. He observed that majority of the farmers used aqueous formulations of leaves or seeds for protecting their crops. They indicated that these materials were collected from trees on communal lands. Eight percent of users indicated that they used commercial formulations, which are imported by the Jeloise Company Limited, Kumasi, and distributed via their own network of retailers and Ministry of Agriculture shops. Most farmers using neem for crop protection had gained their information from extension programmes and organizations.

## 2.15 ECOLOGY OF NEEM

Neem can grow in tropical and subtropical regions with semi-arid to humid climates. It can grow well in areas with annual rainfall of 400-1200mm and at elevations from sea level to 1000m. At higher altitudes (1000-1500), growth may be slow. The best soils are deep, well drained and sandy (Schmutterer, 1995), although the range of soils on which it can grow is also wide. Soil water availability appears to be the most critical factor (Fishwick, 1970). According to Ogemah (2003), neem can grow on both alkaline and saline soils with a pH of 6.2 – 7.0 although pH of 5.9 and 10.0 may also be tolerated. Optimum temperatures range between 21-32$^0$C. The tree can tolerate temperatures as high as 50$^0$C, but low temperatures below 40$^0$C are unfavourable. According to Childs *et al.* (2001), the neem tree is drought-tolerant, and thrives in many of the drier areas of the world. There is, therefore, considerable interest in neem as a means to prevent the spread of deserts and ameliorate desert environments far in Saudi Arabia (Ahmed, *et al.*, 1989), and sub-Saharan Africa (National Research Council, 1992).

## 2.16 CHEMICAL COMPOSITION OF NEEM

Neem products have been used for many years, especially in India and neighbouring countries, in the control of insect pests. Despite the limited scientific investigations, the beneficial properties of neem have been appreciated by the people in these areas (Ogemah, 2003). About 413 different species/subspecies of insect pest listed by Schmutterer (1995) have been found to be susceptible to neem products. The listed species/subspecies belong to different insect orders most of them were Lepidoptera and Coleoptera (Schmutterer, 1987, 1995).

### 2.16.1 Active ingredients of neem

Several biologically active compounds have been isolated from different parts of neem tree. Several vilasinin derivatives, salanins, salanols, salasnolactomes, vepaol, isovepaol, epoxyazadirachdone, gedunin, 7-deacetylgedunin have been isolated from neem kernels. Azadirachtin is however, the most potent growth regulator and antifeedant (Butterworth and Morgan, 1968; Warthen, *et al*., 1978; Ahmed, 2000).

### 2.16.2 Chemical structure and biosynthesis of azadirachtin

The triterpenoid azadirachtin was first isolated from the seeds of the tropical neem tree by Butterworth and Morgan (1968). Its definite structural formula ($C_{35}$ $H_{44}$ $O_{16}$), which resembles that of ecdysone, was finally explained by Kraus *et al*. (1985) and Bilton *et al.* (1985). Azadirachtin is a highly oxidized limonoid whose biosynthesis involves a series of oxidation and rearrangement reactions (Mordue and Blackwell, 1993). The fruit is the most important part of neem that affects insects in various ways. The leaves, which may also be used for pest control, may reach a length of 30 cm (Hydra, 1998). Neem oil contains most of the azadirachtin found in neem products and is often the leading starting material for the manufacture of insecticides or extraction of azadirachtin. The bioactivity of neem oil is usually highly correlated to the content of azadirachtin (Isman and Port, 1990; Ogemah, 2003). Some of the most important properties of the oil are arachidic acid, linoleic acid, stearic acid and oleic acid (Kumar, 1997).

### 2.16.3 Mode of action of neem products

#### 2.16.3.1 Insect growth regulation

To understand the mode of action of azadirachtin with respect to growth and metamorphosis, it is important to have a general understanding of the hormonal control of growth and development in insects. Hormones are responsible for the regulation of growth and development. The most important are the moulting hormones (Ecdysteroids) and juvenile hormones which are synthesized in the prothoracic glands of insects (Ogemah, 2003). The synthesis of ecdysone is triggered by the prothoracicotropic hormone (PTTH), which in turn is synthesized in the lateral neurosecretory cells and released through the corpus cardiacum and corpus allatum. During the feeding period of the larva, juvenile hormone inhibits ecdysone synthesis (Chapman, 1998). A major action of azadirachtin seems to be the modification of the haemolymph ecdysteroid titres. Contrary to earlier expectations, it has been shown that azadirachtin does not act directly on prothoracic glands and it also does not bind to ecdysteriod receptors (Koul, *et al.*, 1987; Koolman, *et al.*, 1988). Azadirachtin depresses the synthesis of neurohormones from the brain as well as their release from the corpus cardiacum. The insect growth regulation effects of azadirachtin manifest as developmental aberrations in immature insects and are both dose and time dependent; can cause death before and during the moult, or delay of the moult (Rembold, 1995). Azadirachtin also inhibits the synthesis and release of Juvenile hormone possibly by affecting the release of allatotropins into the corpus allatum. Many of the manifestations of azadirachtin effect on moulting may therefore be linked to the balance between both the presence and absence of ecdysone and juvenile hormone (Rembold, 1995). These include delay in moulting (Langewald and Schmutterer, 1992), lack of differentiation of tissues (Schluter, 1985, 1987), and black spots (Hori, *et al*., 1984; Malczewska, *et al*., 1988).

**2.16.3.2 Oviposition behaviour**

The females of some lepidopterous insects are repelled by neem products on treated plant parts or other substrates and will not lay eggs on them under laboratory conditions. This has been observed in the cabbage webworm, *Crocidolomia binotalis,* the Afro-Asian cotton bollworm, *Helicoverpa armigera,* and the fall armyworm, *Spodoptera frugiperda* (Schmutterer, 1997; Panhwar, 2005). The dipterous insect, *Lucilia serricata,* was also deterred from egg lying, as were some beetles (*Callosobruchus* spp.) (Ahmed, 2000).

**2.16.3.3 Feeding behaviour**

Azadirachtin is a potent insect antifeedant. The antifeedant effects of azadirachtin have been reported for many species of insects (Warthen, 1989; West and Mordue, 1992). Trials carried out by Gill and Lewis (1971) showed that desert locusts *(Schistocerca. gregaria*), were deterred from feeding on the aerial parts of plants growing in treated composts as a result of systemic movement of azadirachtin from roots of bean plants. Azadirachtin completely inhibited feeding of the very sensitive locust when it was offered on sucrose-treated filter paper as a 1.5-6 X.10-8M solution, i.e. 10-40 g/1- (Butterworth and Morgan, 1968; Haskell and Schoonhoven, 1969). Reduction of feeding was also observed after topical application or injection of neem derivatives, including azadirachtin and alcoholic neem seed kernel extract (Schmutterer, 1995). This means that the reduction of food intake by insects is not only gustatory; the sensory organs of the mouth parts also regulate feeding in the insects. These two phagodeterrent and antifeedant effects were called primary and secondary (Schmutterer, 1995). When given by injection to tobacco hornworm caterpillars, *Manduca sexta*, the allelochemical azadirachtin inhibits growth without reducing food intake (Hori, *et al*., 1984).

**2.16.3.4 Fitness (vigor; quality)**

A study by Mordue and Blackwell (1993) on the effect of azadirachtin on tissues of some insects showed that the application of azadirachtin caused most of the insects to lose their vigour or fitness. According to Dorn *et al*. (1987), the fitness of insects is often reduced after application of low dosages of azadirachtin but moulting is not disrupted. Adults resulting from such treatments are for instance unable to copulate, such as males of *Oncopeltus fasciatus* (Dorn, 1986) or cannot recognize the male pheromone, as in females of the fruit fly *Ceratitis capitata* (Schmutterer and Wilps, 1995). In some Coleopteran neem ingredients caused a prolongation of lifespan of the adults, in others, a reduction. In homopterous insects, the longevity was negatively influenced by neem derivatives (Ahmed, 2000).

#### 2.16.3.5 Reproduction

Neem and azadirachtin have shown several adverse effects on ovarian development, fecundity, and fertility of various insects (Karnavar, 1987). Azadirachtin has been shown to inhibit oogenesis and ovarian synthesis in *Locusta migratoria* (Rembold and Sieber, 1981). Reduced fecundity was demonstrated in *Spodoptera exempta* (Tanzulbil and McCaffrey, 1990) and *Liriomyza trifolii* (Parkman and Pienkowski, 1990).

## 2.17 ADVANTAGES OF THE UTILIZATION OF NEEM PRODUCTS

### 2.17.1 Safety to beneficial and non-target species

One of the major problems with synthetic insecticides is their toxicity to non-target species. Many synthetic insecticides have been known to kill beneficial species and in some cases leading to the emergence of more difficult pest problems (Tetteh and Glover, 2008). Neem on the other hand has proved to be fairly safe to beneficial species. Sontakke and Dash (1996) noted that the number of the beneficial pollinator bees, *Apis flora*, in mustard was normal after the use of neem insecticides. Neem products have also been known to be safe against various predaceous spiders and mite (Mansour, *et al*., 1987, 1993, 1997). Schmutterer (1997) concluded that neem products are, despite the effect on numerous insect pests, safe to spiders, adults of many beneficial insects and eggs of predators. Ogemah (2003), noted that the number of *Teretriosoma nigrescens* a predator of *Prostephanus truncatus* was not significantly reduced when treated with neem formulations.

### 2.17.2 Low mammalian toxicity

Neem generally has limited or no toxicity to humans. According to Hydra (1998), many reports have confirmed neem as a safe product to human beings. Its long-term direct use such as mixing with food during storage, consumption in medicinal concoctions and utilization of stems as tooth brush, is a clear demonstration of this. Again, neem leaves have been chewed for a long time without any adverse effects (Schmutterer and Acher, 1987). In safety tests published by the National Research Council (1992), neem products particularly Margosan-O, were found to be safe to mallard ducks, rats and rabbits. The acute oral $LD_{50}$ of Margosan-O was in excess of 16ml/kg body weight to mallard ducks and 5ml/kg to rats. This according to Boeke *et al*. (2004) makes neem useful in the control of storage pests since it may be mixed with food and safely consumed. Boeke *et al.* (2004) concluded that considering that there are many cases of chemical poisoning in the world, the use of neem products would reduce cases that occur during application of chemicals and consumption of treated food.

KNUST

### 2.17.3 Pest resistance

The problem of pest resistance to insecticide has increased over the last decade and has become a major obstacle to increased food production. The problem of multiple resistances poses an even greater danger to agricultural production (National Research Council, 1992). Interestingly, neem has been demonstrated to control agricultural insect pests showing resistance such as *Spodoptera littoralis* (Behera and Satapathy, 1996) and *Bemesia tabaci* (Dimetry, *et al*., 1996; Ahmed, 2000). The National Research Council (1992) attributed this partly to the many complex compounds found in neem products and its unique mode of action related to growth regulation only in insects. So far no insect has shown complete resistance to neem products although some cases have been reported, mostly involving refined neem products (Panhwar, 2005). While Vollinger (1987) reported lack of resistance of *Plutella xylostella* to neem seed kernel extract, Kao and Cheng (2001), reported resistance of *Plutella xylostella* against azadirachtin.

### 2.17.4 Availability of neem products

According to Boeke *et al*. (2004), many of the small scale farmers in many developing countries are unable to purchase chemicals for the control of field and storage insect pests. In some cases, the chemicals are only available in the major towns. Since neem trees can be grown by farmers on their own farms, it would increase the availability and affordability of neem products for stored products (Boeke, *et al*., 2004).

### 2.17.5 Use of neem products

Neem has found application in a wide range of areas. This is particularly useful to its acceptability. Neem products are useful for insect pest control in crop production, medicinal, industrial products, public health, reforestation, birth control, provision of fuel wood, provision of timber and soil fertility improvement (National Research Council, 1992).

KNUST

### 2.17.6 Adaptability

The neem tree is widely adapted to different growth conditions including poor soils and low moisture. It is adapted to a wide range of climate, from hot weather with shade temperatures of $49^0$C to as low as $0^0$C on altitudes up to 1500m (Hedge, 1993). It can also withstand drought and saline conditions (Schmutterer, 1988; Panhwar, 2005). It can therefore be grown in most parts of Ghana.

## 2.18 SOME CONSTRAINTS IN THE USE OF NEEM PRODUCTS

The use of neem products is not without constraints and limitations. It is important to view these limitations and constraints as challenges whose solving could create new opportunities in the utilization of neem products (Ogemah, 2003). One of the greatest limitations that the use of neem products poses is the lack of standardization of the products. Most often it is quite difficult to recommend specific dosages since products differ considerably in their contents (Isman, 2006). For instance in Ghana, it has been reported that farmers have had successes with 30g of seed kernel / litre of water in controlling some insect pests of cabbage (FAO 2000). In Sudan, 50g of seed kernel/litre of water has been reported to be effective against some insect pests of okra (Ahmed, 2000). Childs *et al.* (2001) and Hydra (1998) have suggested 25-50 g of seed kernel / litre of water to be effective against most insect pests. It is therefore obvious that there is the need for standardization in the use of neem products.

Handling and application of crude neem products are also difficult since bulky quantities are involved. Therefore the use of such products in large-scale agriculture may not be practical in the near future (Ogemah, 2003). Again some neem products have been reported to be unstable, and degrade fast under the sun's ultraviolet rays (National Research Council, 1992). Furthermore, neem products are slow acting, and occasionally result in incomplete mortality compared to conventional synthetic insecticides and may hence not be readily acceptable to farmers (Isman and Port, 1990).

KNUST

# CHAPTER THREE

## MATERIALS AND METHODS

### 3.1 STUDY AREA

The field experiments for the minor and major seasons were carried out on an experimental farm near the premises of Kwame Nkrumah University of Science and Technology (K.N.U.S.T) sewage treatment plant. This experimental farm has ample supply of water throughout the year.

### 3.2 TARGET CROP

The 'Power' variety of Tomato (*Lycopersicon esculentum*) was used since this is the most popular variety cultivated by tomato farmers in Ghana especially in Southern Ghana.

### 3.3 SEEDLING PREPARATION

The seeds were nursed on a nursery bed of size 3m x 2.2m on 13$^{th}$ October 2008 for the Minor season and on 1$^{st}$ June 2009 for the Major season. A soil mixture of sandy loam was used for preparing the bed. Seeds were sown in drills about 10cm apart at a depth of about 5mm. The distance between two stands was 20cm. A nutrient solution of 25g NPK in 15litres of water was used to water the seedlings a week later (Bonsu, 2002).

### 3.4 EXPERIMENTAL DESIGN

There were four (4) treatments with three (3) replications for each treatment. The treatments were as follows:

- 30g of Aqueous Neem Kernel Powder Extract (ANKPE) applied on tomato plant
- 30g of Neem Kernel Powder Extract (NKPE) applied in the soil
- No chemical application (control)
- 2ml/litre of Karate (used as reference chemical insecticide)

The effects of the above listed treatments were studied against whitefly (*Bemisia tabaci*).

The field design used was the Randomized Complete Block Design (RCBD) with a total plot size of 21.6m$^2$. The plots were spaced 1m apart. A spacing of 60cm x 60cm was adopted for each plot and there were 20 plants on each plot. Healthy and vigorously growing seedlings were selected and one seedling was planted per hole. The seedlings were transplanted on 27th October 2008 for the Minor season and 15$^{th}$ June 2009 (Major season) to their permanent beds.

KNUST

### 3.5 CULTURAL PRACTICES

The normal agronomic practices (e. g. watering, weeding, fertilization and disease control) recommended for growing vegetables in an experimental farm taken from 'Vegetable and Spice Crop production in West Africa' (Obeng-Ofori, *et al.*, 2007) were followed.

### 3.6 PREPARATION OF NEEM KERNEL EXTRACTS

#### 3.6.1 Aqueous Neem kernel Powder Extract (ANKPE) applied on plants

The ripe fruit pulps were removed from the seeds immediately after harvest. The seeds were then laid out in a thin layer of plastic sheet and dried at room temperature. Two hundred (200) grams of dried fruits of neem were crushed lightly to break them by using mortar and a pestle. The loose shells were then removed by winnowing. The crushed seeds were stored in baskets with plenty of air to prevent moulds from growing on the seeds. After their separation, the seeds were ground into powder using an electronic blender.

Thirty (30) grams of the powder was dissolved in one litre of distilled water to form a mixture. The mixture was then left to stand for 5 hours. The mixture was constantly stirred with a stick to ensure that the extraction process was thorough. The solution was filtered through fine gauze to remove the bigger particles. The filtered solution was then topped up to 15 litres in a knapsack sprayer for field application.

### 3.6.2 Neem Kernel Powder Extract (NKPE) applied into the Soil

Six hundred (600) grams of dried fruits of neem were crushed lightly with mortar and pestle to break them. After their separation, the seed kernels were ground into a powder using an electronic blender.

### 3.6.3 Synthetic chemical insecticide

2 millilitres of Karate (Lambdacyhalothrin) per litre of water was used for comparison with the two neem extracts.

## 3.7 APPLICATION OF CHEMICALS

The application of the neem extracts was carried out two weeks after transplanting. Foliar sprays were applied 6 times at one week interval between applications. This was done as neem products breakdown rapidly. The rate of application was 30g/l of water. The application of the ANKPE on plant leaves was done by using the knapsack sprayer.

Neem powder was applied by hand into small holes around the plant base into the soil at a rate of 7.5g/plant two weeks after transplanting of the seedlings. The neem kernel powder was applied 6 times with one week interval between applications.

The application of the synthetic insecticide Karate (Lambdacyhalothrin) was done using a separate knapsack sprayer at the rate of 2ml/litre of water. Spraying was done 6 times with one week interval between applications. The applications of all control measures were done in the evening. This increases the efficiency of the applied chemicals.

## 3.8 DATA COLLECTION

### 3.8.1 Insect numbers

A preliminary count was carried out one week after transplanting. This was done before the application of the neem extracts and the karate to determine the presence of target insects on the tomato plants. This was done by counting the number of insects on 15 different plants which were selected randomly from each plot. On each plant, 5 leaves were selected; two from the upper, one from the middle, and two leaves from the lower section of the plant. This was done since both mature and immature target insects can cover the whole plant.

Actual counting started two weeks after transplanting. Counting was done twice in a week with 3 days interval from the 2$^{nd}$ to the 5$^{th}$ week after transplanting. This was later reduced to once in a week in the 6$^{th}$ and 7$^{th}$ weeks. The average number of each insect species counted each time was computed for each treatment and recorded.

**3.8.2. Damaged leaves**

The number of leaves which showed symptoms of tomato yellow leaf curl virus per plant was counted to study the effects of the treatments on target and non-target insect pests. The number of plants selected was 15, as it was described in 3.8.1

**3.8.3 Infected plants**

In order to study the effects on the whiteflies, the number of the infected plants in each plot was counted. For the whiteflies (*B. tabaci*) all plants which showed symptoms of tomato yellow leaf curl virus as described by Brown *et al*. (1995) and Gilbertson, (2008) were counted as infected plants.

**3.8.4. Climatic data**

Data on climatic factors during the period of study as such rainfall, relative humidity and temperature, were obtained from the Meteorological Unit of the Kwame Nkrumah University of Science and Technology.

**3.8.5 Yield analysis**

Ripped tomato fruits were harvested for a period of 4 weeks at 4 days intervals. The weight of the collected fruits in each plot was recorded. The yields from the control and karate sprayed plants were used as comparison with the two neem products. The weight of harvested fruits per plant per week was adopted in determining the yield of each plot.

### 3.9 STATISTICAL ANALYSIS

SAS (2003 edition) was used to determine the analysis of variance (ANOVA) for mean number of *Bemisia tabaci*. Where the difference was significant, the means were separated by Student-Newman-Keuls Test (SNK: $P \leq 0.05$).

KNUST

# CHAPTER FOUR

## RESULTS

### 4.1 INSECT PESTS ENCOUNTERED ON THE TOMATO PLANTS

Results obtained from the field experiment indicated that in addition to whiteflies (*Bemisia tabaci*), other insect pests such as African mole cricket (*Gryllotalpa africana*), cabbage looper (*Trichoplusia ni*) and the African bollworm (*Helicoverpa armigera)* attacked the tomato plants. Mole crickets were detected 3 days after germination of the seeds. They cut down few of the seedlings in the first week of germination during the minor season. However, the number of seedlings cut down reduced to 5 plants in the major season. *Trichoplusia ni* was detected on the plants one week after transplanting during the minor and major seasons (Tables 1 and 2).

**Table 1: Total number of *T. ni* on each treatment weeks after transplanting (Minor season, 2008)**

| Treatments | Week 1 | Week 2 | Week 3 |
|---|---|---|---|
| Control | 2 | 10 | 2 |
| Karate | 1 | 2 | 0 |
| ANKPE | 1 | 3 | 0 |
| NKPE | 1 | 4 | 0 |

**Table 2: Total number of *T. ni* on each treatment weeks after transplanting (Major season, 2009)**

| Treatments | Week 1 | Week 2 | Week 3 |
|---|---|---|---|
| Control | 5 | 6 | 7 |
| Karate | 1 | 5 | 2 |
| ANKPE | 4 | 2 | 0 |
| NKPE | 2 | 5 | 3 |

KNUST

In the minor season, the control recorded the largest number of 14 caterpillars, whilst karate - sprayed plants recorded the least number of 3 caterpillars, two weeks after transplanting (Table 1). ANKPE and NKPE treated - plots recorded 4 and 5 caterpillars respectively in the minor season (Table 1). No *T. ni* was spotted on the ANKPE and NKPE treated – plots, 3 weeks after transplanting (Table 1). However, the total number on the control plots increased to 14 caterpillars, 3 weeks after transplanting (Table 1). The number of *T. ni* in the major season increased compared to the minor season. The control recorded the largest number of 18 caterpillars whilst the ANKPE - treated plots had the least number of 6 caterpillars (Table 2). Karate and NKPE treated - plots recorded 8 and 10 caterpillars respectively (Table 2). The number of *T. ni* reduced to 2 and 3 caterpillars on the Karate - sprayed and NKPE - treated plants respectively, 3 weeks after transplanting (Table 2). The caterpillars did not cause any observable economic damage to the plants. No *T. ni* was spotted on ANKPE - sprayed plants during the major season at 3 weeks after transplanting (Table 2).

The African bollworm (*H. armigera*) was detected 8 weeks after transplanting in both the minor and major seasons. In the minor season, the control recorded the largest number of 6 fruits damaged whilst karate - sprayed plants recorded no fruit damage (Table 3). NKPE -

treated plants had 3 fruits damaged whilst ANKPE - sprayed plants had one fruit damaged (Table 3).

**Table 3: Total number of fruits damaged by *H. armigera* on each treatment 8 weeks after transplanting in the minor and major season**

| Treatments | Number of fruits damaged | |
|---|---|---|
| | Minor season (2008) | Major season (2009) |
| Control | 6 | 3 |
| Karate | 0 | 0 |
| ANKPE | 1 | 0 |
| NKPE | 3 | 0 |

In contrast, the control recorded 3 fruits damaged whilst no fruit was damaged in all the treated plants during the major season (Table 3).

## 4.2 POPULATION DYNAMICS OF WHITEFLY (*BEMISIA TABACI*)

*Bemisia tabaci* was first encountered on all treatments two weeks after transplanting in the minor season (Fig.1) and major season (Fig.2). The first application of the control measures in the second week did not result in any significant reduction in numbers of *B. tabaci*. In the minor season, the number of whiteflies continued to build up to the 4$^{th}$ week with the control recording the largest number of 41.0, whilst the karate - sprayed plants recorded the least number of 19.0 (Fig.1). *B. tabaci* population reached its peak during the 5$^{th}$ week on all treatments (Fig.1). The largest number of 385 was recorded on the untreated (control) plants, whilst the least of 133.0 was recorded on the karate - sprayed plants during the minor season (Fig.1). NKPE - treated plants recorded a mean of 256 whiteflies whilst ANKPE - sprayed plants followed with a mean of 151, five weeks after transplanting (Fig.1).

The build up of whiteflies in the major season, followed a similar trend as was observed during the minor season (Fig.2). However, the number of *B. tabaci* recorded in the 4th and 5th weeks in the major season was lower for all treatments compared to larger numbers recorded in the minor season (Fig.1 and 2).

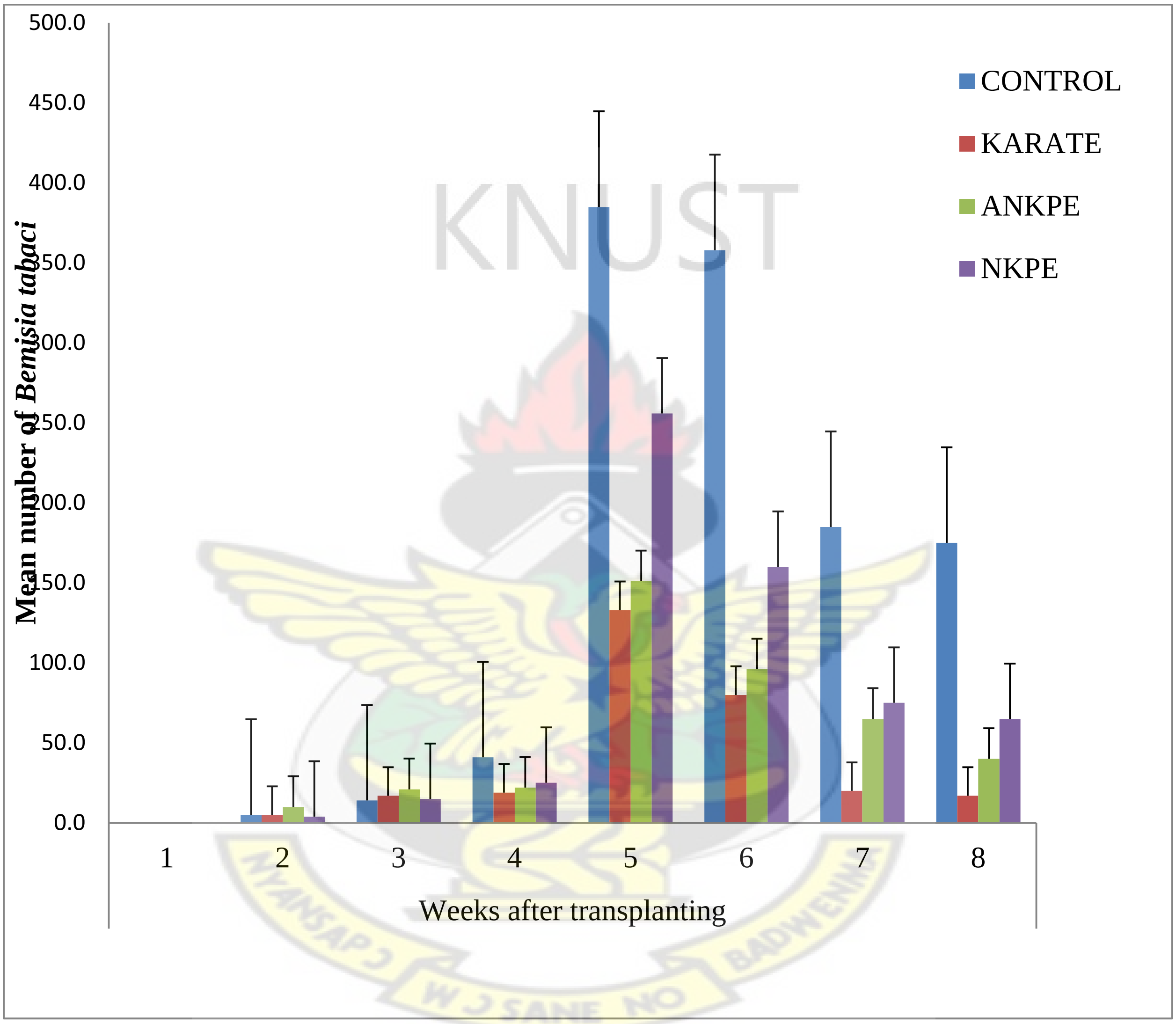


**Figure 1: Effect of pesticides on the number of whiteflies (Minor season, 2008)**

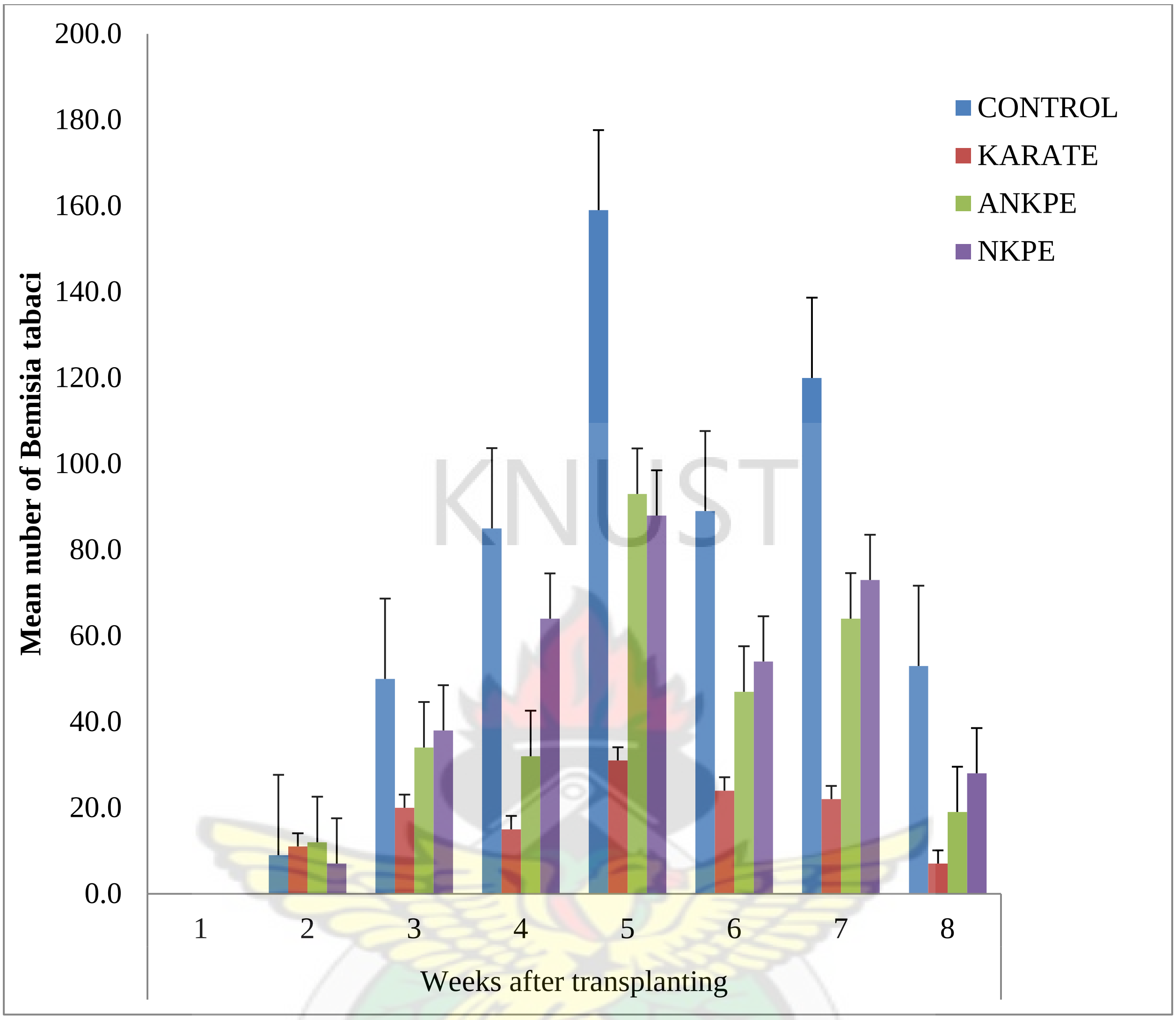


**Figure 2: Effect of pesticides on the number of whiteflies (Major season, 2009)**

During the major season, the control recorded the largest number of 85 whiteflies whilst the karate - sprayed plants recorded the least of 15 whiteflies, 4 weeks after transplanting (Fig.2). *B. tabaci* population reached its peak during the 5th week with the control recording the largest number of 159 whilst the karate - sprayed plants recorded 31 (Fig.2). The ANKPE - sprayed plants recorded a mean of 93 with NKPE - treated plants following closely with a mean of 88, five weeks after transplanting (Fig.2).

At the end of the 4th week, the plants had developed dense canopy on all the plots in the minor and major seasons. The whiteflies could be seen clustered on and beneath the plant leaves. Low rainfall was recorded in the minor season as compared to high rainfall during the major season (Tables 4 and 5). However, temperature and relative humidity were high in both seasons (Tables 4 and 5).

**Table 4: Mean monthly figures of rainfall, temperature and relative humidity (Minor season, 2008)**

| Month | Rainfall (mm) | Temperature ($^0C$) Minimum | Maximum | Relative humidity (%) |
|---|---|---|---|---|
| October | 3.1 | 21.6 | 31.3 | 85.0 |
| November | 1.0 | 22.2 | 32.7 | 84.2 |
| December | 1.5 | 21.1 | 32.6 | 84.0 |
| **Total average** | **5.6** | **21.6** | **32.6** | **84.4** |

**Source:** Meteorological Station, Kwame Nkrumah University of Science and Technology, Kumasi (2008).

**Table 5: Mean monthly figures of rainfall, temperature and relative humidity (Major season, 2009)**

| Month | Rainfall (mm) | Temperature ($^0C$) Minimum | Maximum | Relative humidity (%) |
|---|---|---|---|---|
| June | 12.3 | 22.1 | 31.7 | 87.0 |
| July | 0.6 | 21.4 | 29.6 | 88.0 |
| August | 6.8 | 21.7 | 28.6 | 90.0 |
| **Total average** | **19.7** | **21.7** | **30.0** | **88.3** |

**Source:** Meteorological Station, Kwame Nkrumah University of Science and Technology, Kumasi (2009)

KNUST

**Table 6: Total number of whiteflies counted dead in each treatment weeks after transplanting (Major season, 2009)**

| TREATMENTS | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 |
|---|---|---|---|---|---|---|
| CONTROL | 0 | 0 | 0 | 0 | 60 | 25 |
| KARATE | 0 | 0 | 0 | 0 | 8 | 6 |
| ANKPE | 0 | 0 | 0 | 0 | 22 | 10 |
| NKPE | 0 | 0 | 0 | 0 | 30 | 19 |

The high rainfall (Table 5) during the major season contributed to a reduction in the number of whiteflies on all treatments. In the 5th week, 60, 8, 22, and 30 whiteflies in the control, karate, ANKPE and NKPE respectively, were found dead at the base of the plants after it had rained. In addition 25, 6, 10 and 19 whiteflies in the control, Karate, ANKPE and NKPE respectively, were counted dead at the end of the 6th week on all treatments (Table 6).

The 5th application of the two neem extracts during the 6th week significantly reduced the numbers of *B. tabaci* on the treated plants in the minor and major seasons. In the minor season, the control recorded the largest number of 358 whiteflies, whilst the karate - sprayed plants recorded the least of 80 whiteflies (Fig.1). The number of *B. tabaci* reduced from 151 in the 5th week to 96 in the 6th week for ANKPE - sprayed plants, whilst the number in NKPE reduced from 256 to 160 within the same period (Fig.1). Similarly, the number of *B. tabaci* for ANKPE - sprayed plants reduced from 93 in the 5th week to 47 respectively in the 6th week whilst NKPE reduced from 88 in the 5th week to 54 whiteflies in the 6th week during the major season (Fig.2). It was observed that a large number of whiteflies could not settle on ANKPE and NKPE - treated plants, one day after application. They were seen settling on the treated plants 2 days after application. The final application of the two neem extracts during the 7th and 8th week saw a decrease in the number whiteflies on all treatments in the minor season (Fig1). However, during the major season, there was an increase of whiteflies during the 7th week (Fig.2). The final application saw a reduction in whitefly numbers in the 8th week (Fig.2).

A Pearson product-moment correlation coefficient was computed to assess the relationship between the number of whiteflies on all treatments and temperature in the minor season. In general, there was a weak positive correlation between the two variables (Table 7). Increases in temperature correlated with increases in the number of whiteflies. Similarly, there was a weak positive correlation between the number of whiteflies and relative humidity in all treatments except ANKPE which recorded a negative correlation of -0.099 (Table 8).

**Table 7: Correlation between the number of whiteflies on each treatment and temperature using Pearson product-moment correlation coefficient (Minor season, 2008)**

| **Treatments** | **Number of observations** | **Correlation coefficient (r)** | **P – value** |
|---|---|---|---|
| Control | 39 | 0.193 | 0.239 |
| Karate | 39 | 0.242 | 0.137 |
| ANKPE | 39 | 0.212 | 0.194 |
| NKPE | 39 | 0.209 | 0.201 |

* Correlation is significant at $P \leq 0.05$ (2-tailed)

**Table 8: Correlation between number of whiteflies on each treatment and relative humidity using Pearson product- moment correlation coefficient (Minor season, 2008)**

| **Treatments** | **Number of observations** | **Correlation coefficient (r)** | **P – value** |
|---|---|---|---|
| Control | 39 | 0.066 | 0.691 |
| Karate | 39 | 0.145 | 0.377 |
| ANKPE | 39 | - 0.099 | 0.548 |
| NKPE | 39 | 0.044 | 0.790 |

* Correlation is significant at P ≤ 0.05 (2-tailed)

Overall, there was a weak negative correlation between temperature and the number of whiteflies on all treatments in the major season compared to the positive correlation during the minor season (Tables 7 and 10). Decreases in temperature correlated with reductions in whitefly population during the major season. There was a weak negative correlation between relative humidity and number of whiteflies on all treatments in the major season compared to the weak positive correlation (except ANKPE) in the minor season (Tables 8 and 11). Correlation was significant only on the karate – sprayed and NKPE – treated plants in the major season (Table 10) as compared to minor season (Table 8).A weak positive correlation was established between rainfall and the number of whiteflies in minor season. There were increases in the amount of rainfall. However, the increments did not result in any significant reduction in whitefly numbers (Table 9).

**Table 9: Correlation between number of whiteflies on each treatment and rainfall using Pearson product-moment correlation coefficient (Minor season, 2008)**

| Treatments | Number of observations | Correlation coefficient (r) | P – value |
|---|---|---|---|
| Control | 39 | 0.033 | 0.843 |
| Karate | 39 | 0.118 | 0.474 |
| ANKPE | 39 | 0.121 | 0.462 |
| NKPE | 39 | 0.115 | 0.487 |

* Correlation is significant at P ≤ 0.05 (2-tailed)

**Table 10: Correlation between number of whiteflies on each treatment and temperature using Pearson product -moment correlation coefficient (Major season, 2009)**

| Treatments | Number of observations | Correlation coefficient (r) | P – value |
|---|---|---|---|
| Control | 39 | -0.271 | 0.095 |
| Karate | 39 | -0.333 | 0.038* |
| ANKPE | 39 | -0.295 | 0.068 |
| NKPE | 39 | -0.376 | 0.018* |

* Correlation is significant at P ≤ 0.05 (2-tailed)

**Table 11: Correlation between number of whiteflies on each treatment and relative humidity using Pearson product-moment correlation coefficient (Major season, 2009)**

| Treatments | Number of observations | Correlation coefficient (r) | P – value |
|---|---|---|---|
| Control | 39 | -0.154 | 0.351 |
| Karate | 39 | -0.067 | 0.684 |
| ANKPE | 39 | -0.181 | 0.269 |
| NKPE | 39 | -0.127 | 0.441 |

* Correlation is significant at P ≤ 0.05 (2-tailed)

A weak negative correlation was recorded between the number of whiteflies and rainfall in the major season. However, there was no significant difference between the treatments (Table 12).

**Table 12: Correlation between number of whiteflies on each treatment and rainfall using Pearson product-moment coefficient (Major season, 2009)**

| Treatments | Number of observations | Correlation coefficient (r) | P – value |
|---|---|---|---|
| Control | 39 | -0.133 | 0.493 |
| Karate | 39 | -0.172 | 0.296 |
| ANKPE | 39 | -0.142 | 0.389 |
| NKPE | 39 | 0.024 | 0.885 |

* Correlation is significant at P ≤ 0.05 (2-tailed)

**4.3 NUMBER OF WHITEFLIES**

The karate - sprayed plants recorded the least number of *B. tabaci* whilst the control recorded the largest number of *B. tabaci* in the minor and major seasons (Fig.1 and 2). In the minor season, the result of the statistical analysis (ANOVA) revealed significant difference (F = 194.06) in terms of the number of whiteflies among the various treatments. The SNK showed that the number of *B. tabaci* on the control plants was significantly (P < 0.0001) more than the karate - sprayed plants and neem - treated plants (Table 13). However, the number of whiteflies on the ANKPE - sprayed plants was significantly (P < 0.0001) less than the NKPE - treated plants (Table 13). The number of *B. tabaci* on the karate - sprayed plants was significantly (P < 0.0001) lower than the neem - treated plants (Table 13). However, the number of whiteflies for the aqueous treated plants below the threshold limiting value whilst that of the powder treated plants was just at the threshold limiting value.

**Table 13: ANOVA of the number of whiteflies, damaged leaves and infected plants (Minor season, 2008)**

| TREATMENTS | NUMBER OF WHITEFLIES | DAMAGED LEAVES | INFECTED PLANTS |
|---|---|---|---|
| CONTROL | 387.00 ± 147.78$^{a}$ | 25.00 ± 3.00$^{a}$ | 7.00 ± 2.31$^{a}$ |
| KARATE | 97.00 ± 5.00$^{d}$ | 2.00 ± 0.00$^{c}$ | 0.00 ± 0.00$^{c}$ |
| ANKPE | 135.00 ± 11.53$^{c}$ | 10.00 ± 0.58$^{b}$ | 0 .67 ± 0.33$^{bc}$ |
| NKPE | 200.00 ± 4.97$^{b}$ | 13.33 ± 3.84$^{b}$ | 2.67 ± 1.20$^{ab}$ |

Means within the same column with the same letter are not significantly different at $P \leq 0.05$:

Threshold limiting value (TLV): 200 adult whiteflies/10 leaves (Ahmed, 2000)

**Table 14: ANOVA of the number of whiteflies, damaged leaves and infected plants (Major season, 2009)**

| TREATMENTS | NUMBER OF WHITEFLIES | DAMAGED LEAVES | INFECTED PLANTS |
|---|---|---|---|
| CONTROL | 188.33 + 3.34$^{a}$ | 0.00 | 0.00 |
| KARATE | 43.33 ± 2.19$^{c}$ | 0.00 | 0.00 |
| ANKPE | 100.33 ± 5.46$^{b}$ | 0.00 | 0.00 |
| NKPE | 117.33 ± 9.94$^{b}$ | 0.00 | 0.00 |

Means within the same column with the same letter are not significantly different at $P \leq 0.05$:
Threshold limiting value (TLV): 200 adult whiteflies/10 leaves (Ahmed, 2000)

There was significant difference ($F = 96.38$) among the various treatments during the major season. The number of whiteflies on the karate - sprayed and neem - treated plants was significantly lower ($P < 0.0001$) than the control plants (Table 14). The SNK showed that the number of whiteflies was significantly higher ($P < 0.0001$) in the neem - treated plants compared to the karate - sprayed plants (Table 14). There was no significant difference between ANKPE and NKPE during the major season compared to the significant differences observed in the minor season (Tables 13 and 14). The number of whiteflies of neem-treated plants and karate –sprayed plants fell below the threshold limiting value.

## 4.4 NUMBER OF DAMAGED LEAVES

No leaves were damaged on all treatments from week 1 to week 4 after transplanting of the seedlings (Fig.3). This was as a result of the small number of *B. tabaci* recorded from week 1 to week 4 in the minor season (Fig.1). No damaged leaves were observed at the end of the 8$^{th}$ week in the minor season (Fig.3).

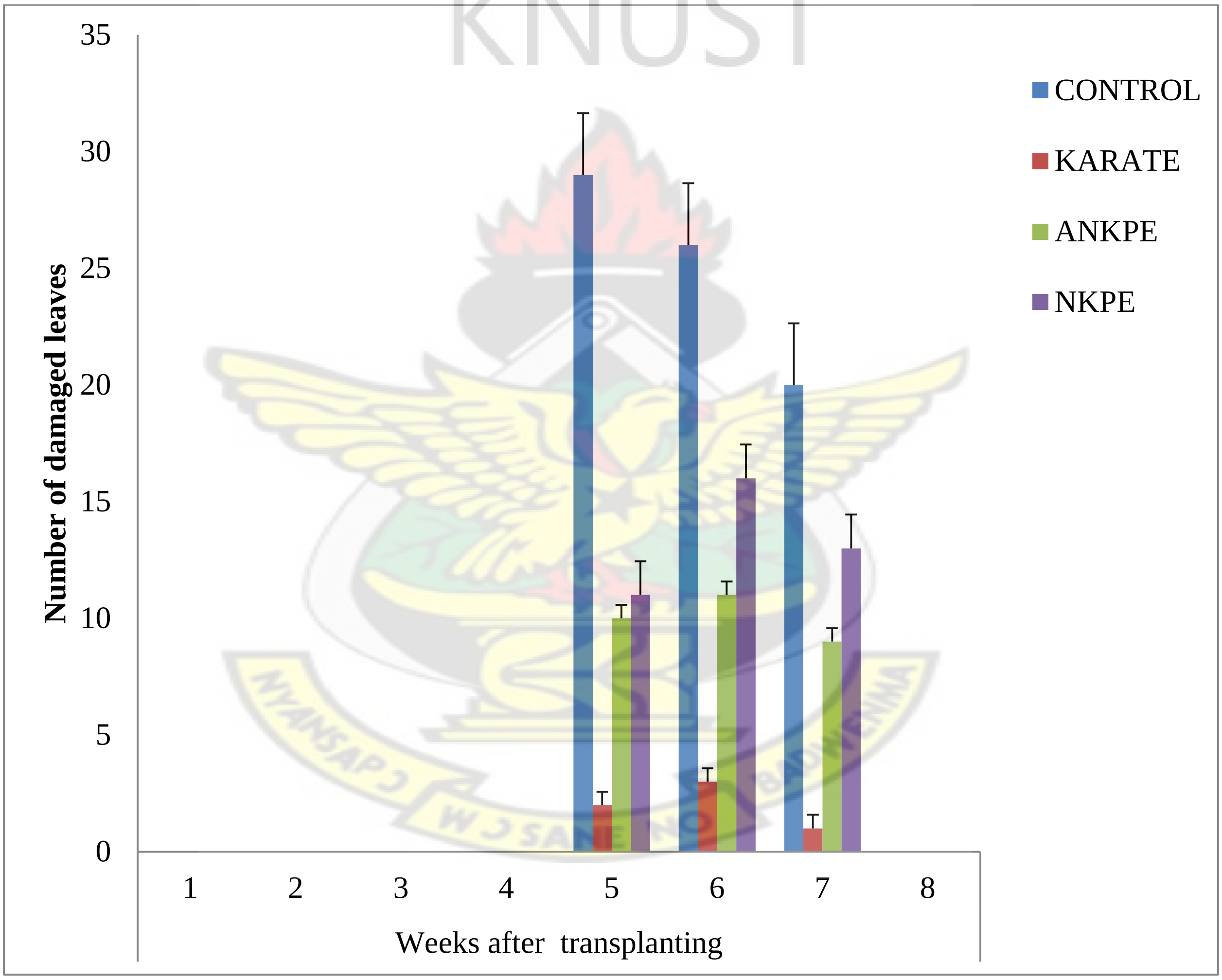


**Figure 3: Effect of pesticides on leave damage (Minor season, 2008)**

Damaged leaves on all treatments were recorded between 5th and 7th week (Fig.3). The control recorded the largest number of damaged leaves whilst the least was recorded on the karate - sprayed plants. The large number of *B. tabaci* on all treatments during the 5th week was accompanied by large numbers of damaged leaves on all treatments (Fig.1 and 3). The 5th and 6th application of aqueous neem kernel powder extract (ANKPE) and neem kernel powder extract (NKPE) reduced the number of *B. tabaci* (Fig.1) which led to a corresponding decrease in the number of leaves damaged by *B. tabaci* on all treatments (Fig.3).

Results from the ANOVA revealed significant difference ($F = 27.92$) among the various treatments. The SNK showed that the number of damaged leaves on the control plants was significantly ($P < 0.0001$) more than the karate - sprayed and neem - treated plants (Table 13). The number of damaged leaves on the karate - sprayed plants was significantly ($P < 0.0001$) lower than the neem - treated plants (Table 13). However, there was no significant difference between the neem - treated plants (Table 13). No tomato leaves showed symptoms of damage by *B. tabaci* on all treatments during the major season compared to the large number recorded during the minor season (Tables 13 and 14).

## 4.5 NUMBER OF PLANTS INFECTED WITH TOMATO YELLOW LEAF CURL VIRUS

Infection of plants with tomato yellow leaf curl virus (TYLCV) on all treatments started in the 5th week which corresponded with the period when the number of *B. tabaci* reached it peak (Fig.1) and large number of leaves were damaged by *B. tabaci* on all treatments (Fig.3). The control recorded a total of 25 plants infected with tomato yellow leaf curl virus (TYLCV) at the end of the application, whilst the karate - sprayed plants recorded no infection in the minor season (Fig.4). The ANKPE - sprayed and NKPE – treated plants recorded a total 3 plants and 10 plants respectively infected with tomato yellow leaf curl virus

(TYLCV). The application of ANKPE reduced the number of infected plants by 92.1% whilst NKPE reduced the number of plants infected by 73.7% compared to the control during the minor season.

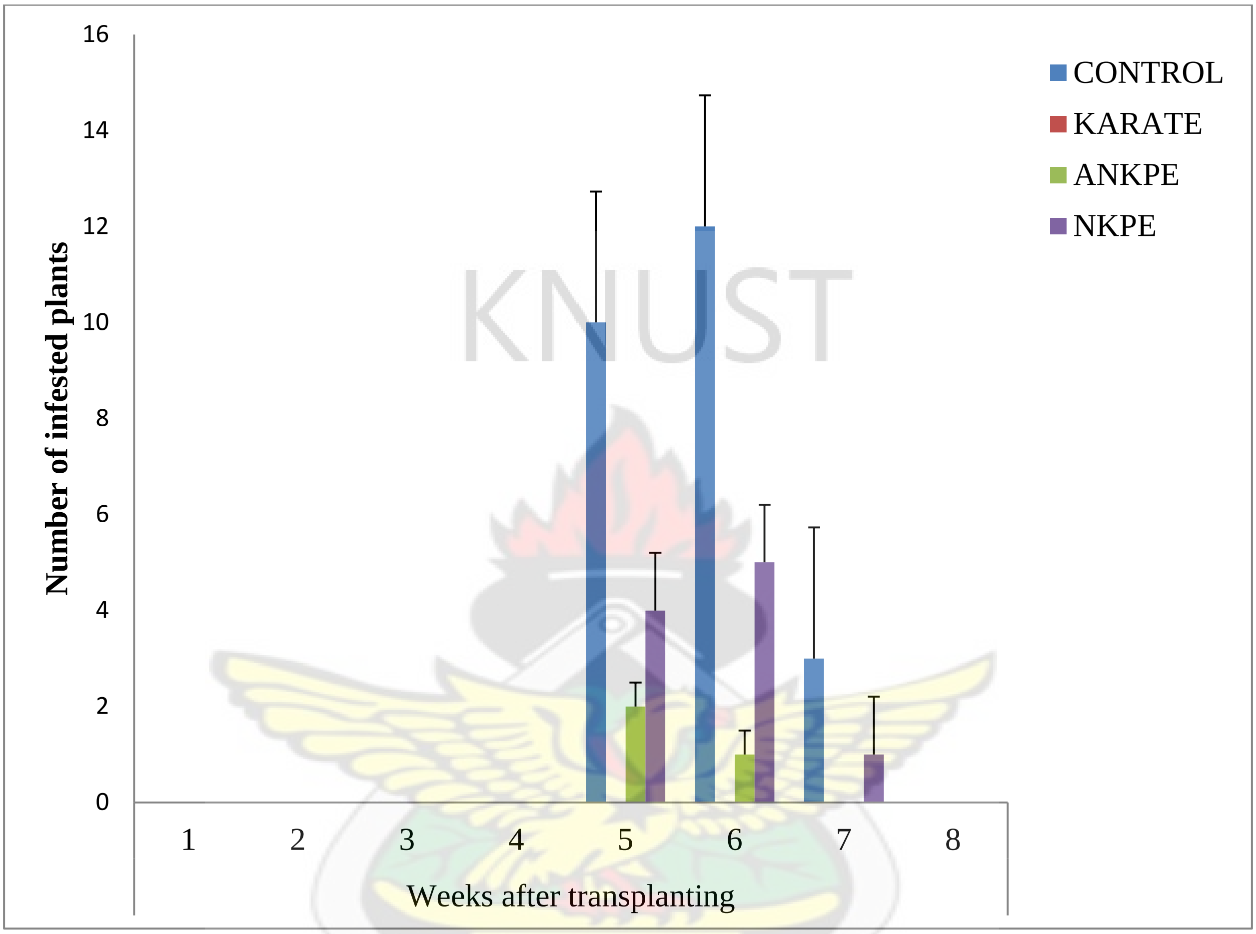


**Figure 4: Effect of pesticides on plants infected (Minor season, 2008)**

The ANOVA showed significant difference (F = 11.54) among the various treatments. The number of plants infested with tomato yellow leaf curl virus in the control was significantly ($P < 0.0001$) more than that on the karate - sprayed and ANKPE - sprayed plants (Table 13). However, there was no significant difference between the control and NKPE (Table 13). Similarly, the karate - sprayed plants did not differ significantly from the ANKPE - sprayed plants (Table 13). The number of plants infested with tomato yellow leaf curl virus in NKPE was not significantly different from ANKPE - sprayed plants (Table 13).

Since no plant leaf showed signs of damaged by *B. tabaci*, no infestation of tomato yellow leaf curl virus (TYLCV) was observed on any plant leaf on all treatments during the major season.

### 4.6 EFFECTS OF PESTICIDES ON THE YIELD OF TOMATO

The tomato fruits were harvested from the 9$^{th}$ week after the final application of the pesticides in both the minor and major seasons. They were harvested when ripped. The highest yield on all treatments was recorded on the 3$^{rd}$ week of harvesting in both the minor and major seasons (Fig.5 and 6). In the minor season, the karate - sprayed plants recorded the highest yield of 5.7kg, whilst NKPE recorded the lowest yield of 1.6kg (Fig. 5).

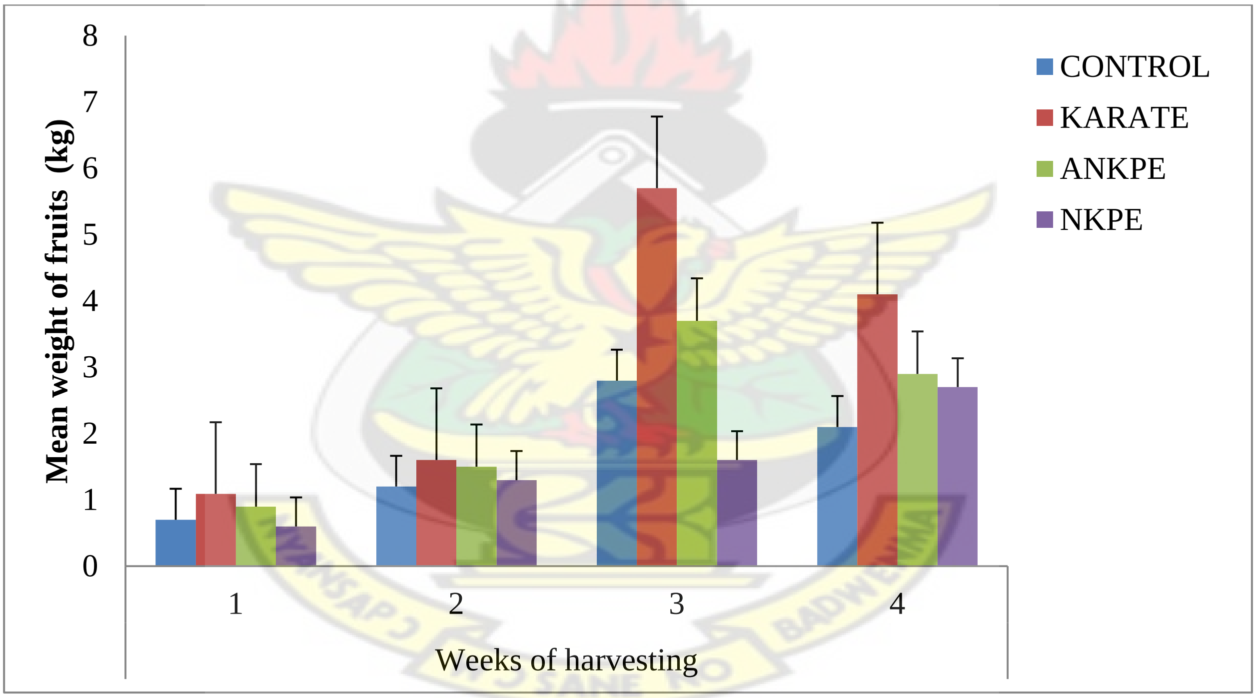


**Figure 5: Effect of pesticides on tomato yield (Minor season, 2008)**

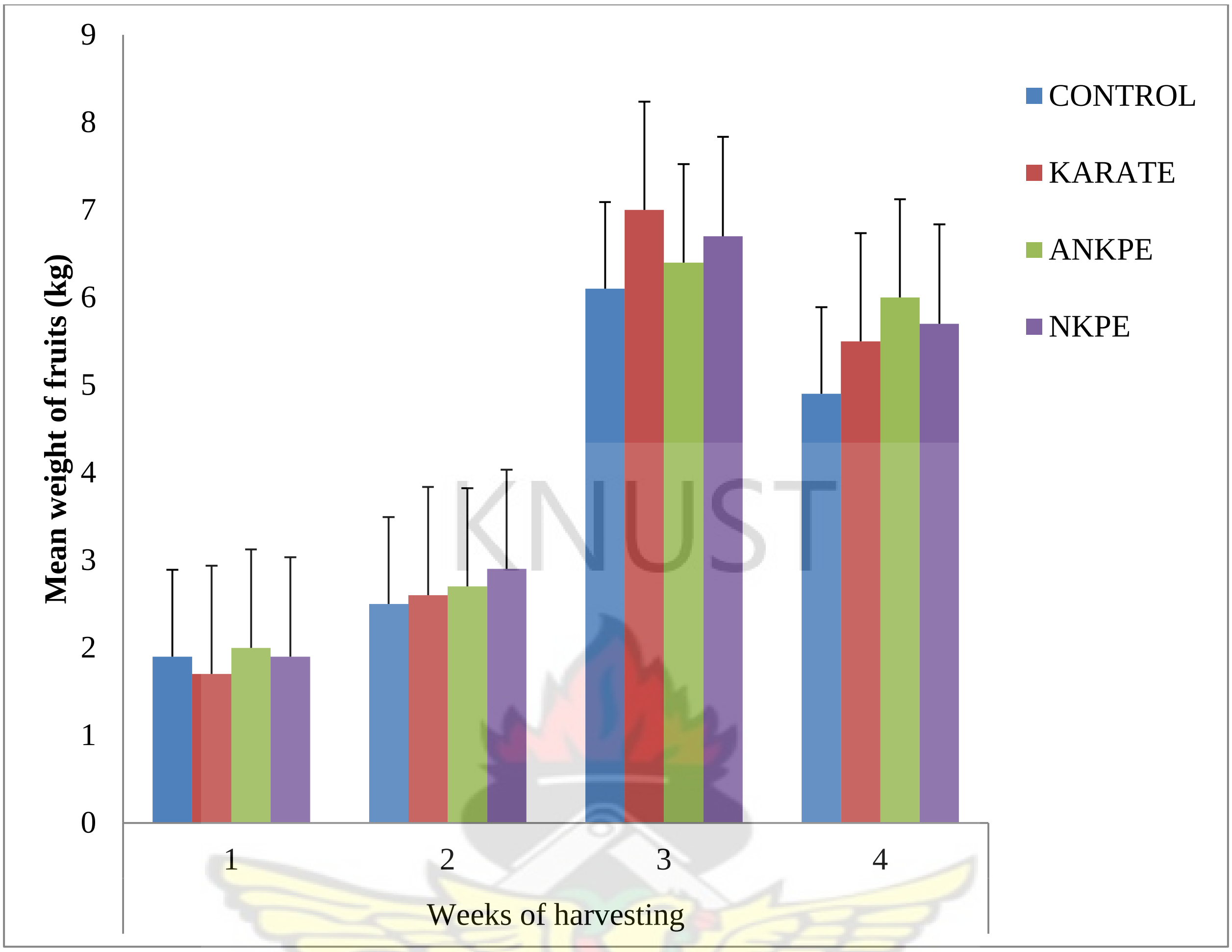


**Figure 6: Effect of pesticides on tomato yield (Major season, 2009)**

The karate - sprayed plants recorded the largest yield of 7.0kg whilst the control recorded 6.1kg in the 3rd week during the major season (Fig.6). At the end of the harvesting period, the karate - sprayed plants recorded the largest total yield of 12.5kg with ANKPE following closely with a total yield of 9.0kg in the minor season (Appendix E). However, in the major season, NKPE recorded the largest total yield of 17.2kg. ANKPE followed closely with 17.1kg (Appendix F). The control plants recorded the least yield of 15.3kg during the major season (Appendix F).

**Table 15: ANOVA of the yield of tomato for each treatment in the minor and major seasons**

| | YIELD (Kg) | |
|---|---|---|
| **TREATMENTS** | **MINOR SEASON** | **MAJOR SEASON** |
| CONTROL | $1.83 \pm 0.12^a$ | $5.10 \pm 0.37^a$ |
| KARATE | $3.17 \pm 0.46^a$ | $5.58 \pm 1.04^a$ |
| ANKPE | $2.06 \pm 0.22^a$ | $5.69 \pm 0.49^a$ |
| NKPE | $2.65 \pm 0.44^a$ | $5.71 \pm 0.45^a$ |

Means within the same column with same letter are not significantly different at $P \leq 0.05$

The ANOVA showed no significant difference ($F = 3.11$; $P < 0.0887$) in yield among the various treatments in the minor season. Similarly no significant difference ($F = 0.19$; $P < 0.897$) was observed among the various treatments in the major season (Table 15).

# CHAPTER FIVE

## DISCUSSION

### 5.1 EFFECTS OF THE NEEM EXTRACTS ON OTHER INSECT PESTS

Cabbage looper (*Trichoplusia ni*) was detected earlier (one week after transplanting) feeding on tomato leaves during the growth period. By the third week, no *T. ni* was detected on the plants treated with ANKPE and NKPE. It was observed that the larvae avoided plants treated with the neem extracts. From this observation, it appears the application of aqueous neem kernel powder extract (ANKPE) and neem kernel powder extract (NKPE) caused disruption in the feeding activity of *T. ni* larvae. This led to a decrease in numbers of *T. ni* during the minor and major seasons (Tables 1 and 2). A study by Levent *et al*. (2005) revealed that the application of neem seed extracts caused disruption in the feeding activity of *Spodoptera exiqua* larvae by a repellent action. The neem extracts therefore proved effective in reducing *T. ni* in both the minor and major seasons.

The African bollworm (*Helicoverpa armigera*) attacked the developing and mature fruit of the tomato plants. They bored into the fruit and fed on the inner parts causing extensive fruit damage. Caterpillars of *H. armigera* were detected when they had entered the fruits. As a result, the caterpillars became less sensitive to the application of the neem extracts. Early stages of *H. armigera* larvae have been reported to be sensitive to the exposure of neem extracts than the advanced stage larvae (larvae already in the fruit) (Levent, *et al*., 2005).

### 5.2 POPULATION DYNAMICS OF WHITEFLY (*BEMISIA TABACI*)

The study of effect of aqueous neem kernel powder extract (ANKPE) and neem kernel powder extract (NKPE) on the population of *B. tabaci* under field conditions helped establish the pattern of distribution of *B. tabaci* on tomato plants during the minor and major seasons. In the minor season, one peak of *B. tabaci* population was observed on all treatments. *B.*

*tabaci* was more abundant in all treatments 5 weeks after transplanting (Fig.1). It was observed that the largest number of *B. tabaci* was present at the vegetative stage of the tomato plants. This was due to the succulent nature of the tomato plants which was due to the abundance of chlorophyll (Shuaib, *et al.*, 2008). It was observed that during the 4$^{th}$ and 5$^{th}$ week, the tomato plants had developed dense canopy which haboured many of the whiteflies. The dense canopies provided a favourable environment for both nymph and adult whiteflies to cluster in large numbers on the underside of the leaves (Martin, 1999).

During the minor season, temperature range of 22.2 – 32.7$^0$C was recorded in the month of November (Table 4). An average relative humidity of 84.2% and a low rainfall of 1.0mm were also recorded in the same period (Table 4). It was observed that the numbers of *B. tabaci* had increased in all treatments three weeks after transplanting (Fig.1). The total number of *B. tabaci* in all treatments had increased from 67 in the 3$^{rd}$ week to 925 in the 5$^{th}$ week (Appendix A). The combination of high temperatures and low rainfall in the minor season might have contributed to the rapid increase in the number of whiteflies on the plants. Ahmed (2000) reported that high relative humidity (80-90%) coupled with relatively high temperatures favoured the development and a sharp increase of whitefly numbers. As a result, the 4$^{th}$ application of ANKPE and NKPE did not result in significant reduction in *B. tabaci* numbers. A study by Shuaib *et al*. (2008) revealed that temperature had significant positive correlation with whitefly numbers. As temperature increases, the number of whiteflies increased (Table 7) in the minor season. Likewise a reduction in temperature resulted in reduction of whiteflies numbers during the major season (Table 9). The 5$^{th}$ and 6$^{th}$ application of ANKPE and NKPE resulted in a reduction in the number of *B. tabaci* in the 7$^{th}$ and 8$^{th}$ weeks after transplanting (Fig.1).

The population dynamics of *B. tabaci* in the major season followed a similar trend as observed during the minor season. However, two peaks of *B. tabaci* population were observed during the 5th and 7th week after transplanting in all treatments (Fig.2). The overall numbers of *B. tabaci* recorded during these times were lower compared to the number recorded in the minor season (Fig.1 and 2). In the major season, a temperature range of 22.1 – 31.7$^0$C and average relative humidity of 87% (Table 5) were recorded 2 weeks after transplanting. These conditions might have contributed to the rapid growth and increase of whitefly numbers in the fifth week (Fig.2) However, high rainfall during the 5th week proved to be a potential mortality factor against *B. tabaci* (Appendices P, Q and R). Large number of whiteflies could be seen lying dead around the base of the plants. The amount of rainfall during the minor season resulted in the death of 30 whiteflies but the numbers were not huge compared to the 180 whiteflies in the major season. Application of the neem extracts resulted in a further decrease in the number of whiteflies in the 6th and 8th weeks after transplanting (Fig.1 and 2).

### 5.3 NUMBER OF WHITEFLIES, DAMAGED LEAVES AND INFECTED PLANTS

The application of aqueous neem powder extract (ANKPE) and neem kernel powder extract (NKPE) reduced the number of whiteflies significantly in the minor season and major seasons. The neem products proved effective against whiteflies, one of the serious insect pests of tomato in Ghana. During the minor season, the karate - sprayed plants recorded the least number of 291 whiteflies, whilst the control plants recorded the largest of 1,163 whiteflies (Appendix A). Plants sprayed with ANKPE recorded a total number of 405 whiteflies which was lower compared to the 600 recorded by NKPE. It appeared that the aqueous extract was able to deter large numbers of adult whiteflies from settling on the plants than the powder extract. This appears to result from the primary and secondary repellent effects and the antifeedant effects of the aqueous extract. The repellent effect of the powder extract appears not to as powerful as the aqueous extract. However, its antifeedant effect is as powerful as the aqueous extract. This is due to the systemic absorption of the azadirachtin from the plant roots to the leaves. The azadirachtin become more concentrated in leaves preventing the whiteflies from feeding on the leaves further. However, the total number of whiteflies recorded by the neem extracts was comparatively lower than the 1,163 recorded by the control plants in the minor season (Appendix A).

In the major season, the ANKPE and NKPE recorded a total of 301 and 352 whiteflies respectively, which was lower compared to the 565 recorded in control plants (Appendix B). The neem extracts recorded a reduction in whitefly numbers which was higher than the control. It was observed that some of the whiteflies could not settle and feed on plants treated with the neem extracts. They were however observed on the plants 2 days after application. Whiteflies which made contact with karate - sprayed plants were found dead at the base of the plants, one day after application. The whiteflies were seen feeding on the plants 5 days later. From these observations, it appears that the effect of ANKPE and NKPE were delayed compared to that of karate. This indicates that the two neem extracts had relatively weak toxicity than that of karate. Schmutterer (1990) observed that most insect pests continue to feed on plants treated with neem products for some time as a result of the delayed effect of neem products. Though the two neem products appeared to have low toxicity, Mordue and Blackwell (1993) reported that contact with neem is known to disrupt food intake due to the toxic effects of neem products. As a result, the amount of food ingested by the insect pest was considerably reduced owing to the secondary antifeedant effect of neem products. The results proved that whiteflies are susceptible to neem products. The reduction in the number of whiteflies during the minor season resulted in fewer leaves damaged by *B. tabaci* on ANKPE and NKPE - treated plants. The difference in damaged leaves between the two neem products was not significant but significantly different when compared with the control. The control plants recorded the largest number of damaged leaves throughout the sampling period than was recorded by the two neem extracts (Fig.3).

Large number of whiteflies settled on the control plants than on the neem - treated plants during the minor season. They avoided the neem - treated plants compared to the control plants indicating that the neem extracts deterred them from settling on the ANKPE and NKPE - treated plots. This led to a drastic reduction in the number of damaged leaves (Fig.3). Griffith *et al.* (1978) observed that crude neem extracts deterred settling and feeding of *Myzus piersicae* on host plants. The control plants recorded the largest number of 25 plants infested tomato yellow leaf curl virus (TYLCV) whilst the karate - sprayed plants recorded no infestation (Appendix D). ANKPE - sprayed and NKPE - treated plants recorded a total of 3 and 10 infested plants respectively which were lower compared to the control plants (Appendix D). The results proved that neem - based compounds are potentially as effective as karate (Lambdacyhalothrin) in the control of whiteflies since there no significant differences was recorded (Table 11).

In the major season, the application of ANKPE and NKPE reduced the numbers of *B. tabaci* considerably than in minor season. The large number of 405 whiteflies recorded on the ANKPE - treated plots in the minor season reduced to 301 individuals during the major season (Appendices A and B). NKPE - treated plots recorded 600 individuals during the minor season which reduced to 352 in the major season (Appendices A and B). Low numbers of *B. tabaci* were recorded throughout the sampling period in all treatments in the major season compared to the large number recorded in the minor season (Fig.1 and 2).

During the major season, the whiteflies settled on the plants 3 days after application of the neem extracts. This was as a result of low temperatures experienced in the major season (Table 5). This might indicate that a slight change in temperature could adversely affect the potency of neem extracts.. When neem extracts are exposed to prolonged light, they begin to lose their ability to control insect pests (Hydra, 1998). However, the residual effect of neem products is prolonged as the low temperatures protect the active ingredient against rapid degradation by light (Heyde, *et al.*, 1983). As a result of these effects of neem, the plots treated with ANKPE and NKPE showed no leaf damage and consequently no infestation of tomato yellow leaf curl virus. The two neem extracts proved efficient in reducing the number of whiteflies and reduced the level of tomato yellow leaf curl virus infestation since the number of whiteflies fell below the threshold limiting value of 200 adult whiteflies/10 plants. It must be added that high rainfall during the major season, contributed to the reduction of *B. tabaci* numbers (Fig.1 and 2). Clean-up measures such as removal of weeds and alternate hosts (Schmutterer, 1969), and correct spacing of plant contributed to the reduction of the population build-up of whiteflies (Sharafel, 1986).

During the sampling period, it was observed that when neem aqueous kernel powder was applied as foliar spray, the leaves of some tomato plants showed symptoms of "burning". This caused some of the leaves to wilt prematurely, 4 days after application. This indicates that high concentrations of aqueous neem kernel extract can cause burning of plant leaves. Users of neem products especially the aqueous extract can avoid this by adhering to the prescribed dosage and avoid over-spraying on plants. .

### 5.4 EFFECTS OF PESTICIDES ON THE YIELD OF TOMATO

In the minor season, the karate - sprayed plants recorded the largest yield of 12.5kg followed by ANKPE - sprayed plants with 9.0kg; the control with 6.8kg and NKPE - treated plants recorded the least yield of 6.2kg (Appendix E). Spraying tomato plants with ANKPE increased tomato yield by 26% over the control. The high yield from the ANKPE - treated plots can be attributed to low number of whiteflies feeding on the tomato plants as compared to the large numbers on plants treated with NKPE (Fig.1). Hydra (1998) reported that neem water sprayed under fruit trees, where fruit flies usually breed and larvae develop, stopped the growth of the larvae into flies.

The yield recorded in the major season was comparatively higher than that recorded during the minor season. The NKPE - treated plots recorded the largest yield of 17.2kg, followed by ANKPE - treated plots with 17.1kg in the major season as compared to the yields of 6.2kg and 9.0kg recorded in the minor season respectively (Appendices E and F). The karate - sprayed plants recorded 16.8kg in the major season as against 12.5kg recorded in the minor season (Appendices E and F). It is possible that the use of fresh and well-stored neem seeds increased the efficacy of neem products against whiteflies and contributed to the high yields recorded; the use of poor quality seeds would have negatively affected the results (Ahmed, 2000).

The least yield of 15.3kg in the major season was recorded by the control plants. The large number of *B. tabaci*, coupled with the large number of plants infested with tomato yellow leaf curl virus contributed to the low yields recorded in the minor season. The results showed that the application of karate (Lambdacyhalothrin) did not prove superior to the neem – based products in terms of yield of tomato; neither did the foliar application of ANKPE proved superior to NKPE - treated plants.

# CHAPTER SIX

## CONCLUSIONS AND RECOMMENDATIONS

### 6.1 CONCLUSIONS

The following conclusions can be drawn from the study:

1. The field trials for the minor and major seasons proved that whiteflies are susceptible to neem - based products.
2. Both the aqueous neem kernel powder extract (ANKPE) and neem kernel powder extract (NKPE) could be used in controlling whiteflies.
3. The foliar application of aqueous neem kernel powder extract (ANKPE) and neem kernel powder extract (NKPE) proved equally effective in reducing the number of whiteflies in the minor and major seasons.
4. The foliar application of aqueous neem kernel powder (ANKPE) and neem kernel powder (NKPE) proved potentially as effective as the application of karate (active ingredient Lambdacyhalothrin).
5. The yields of ANKPE -sprayed and NKPE- treated plants were comparatively not different from that of the karate- sprayed plants.

## 6.2 RECOMMENDATIONS

1. Neem seeds to be used as foliar spray or applied as powder should be well dried and stored in a well ventilated room as the use of poor quality seeds can negatively affect the potency of neem products.
2. The evenings are the more suitable time of day for spray and powder application of neem products because the plants would be able to absorb the active ingredients during the night.
3. The Ministry of Food and Agriculture should intensify education on the use of neem-based extracts in integrated pest management programmes in tomato cultivation since it is environmentally friendly and cheap
4. The Ministry of Food and Agriculture should lead and encourage the commercial production of neem-based formulations to relieve farmers of the laborious processes involved in the collection of the seed kernel and subsequent extraction processes.
5. Since the foliar spray produces a burning sensation, it is recommended that protective clothes should be worn when applying the aqueous extract to avoid contact with the spray.
6. The use of 30g of seed kernel per litre of water proved effective in controlling *B. tabaci*. This result is comparable with that of FAO (2000) which observed that 30g of seed kernel / litre of water proved effective in controlling some insect pests in cabbage in Ghana. It is recommended that 30g of seed kernel per litre of water be used in the control of *B. tabaci* on tomato in Ghana.

7. This study could pave way for further research works by Microbiologists and academia on: the effect of the application of neem powder extracts on beneficial microorganisms in the soil.

KNUST

## REFERENCES

Ahmed, M.M.M. (2000). Studies on the Control of Insect Pests in Vegetables (Okra, Tomato, and Onion) In Sudan with Special Reference to Neem preparations. *University of Giessen, Germany*, pp. 13-31.

Ahmed, S., Bamofleh, S. and Munshi, M. (1989). Cultivation of neem (*Azadirachta indica,* Meliaceae) in Saudi Arabia. *Economic Botany* **43**: 35-38.

Behera, U.K. and Satapathy, C.R. (1996). Screening indigenous plants for their insecticidal properties against *S. litura*, *Insect Environment* **2**, 43 – 44.

Bilton, J. N., Broughton, H.B., Ley, S.V., Lidert, Z., Morgan, E.D., Rzepa, H.S. and Sheppard, R.N. (1985). Structural reappraisal of the limonoid insect antifeedant azadirachtin. *J. Chem. Soc., Chem. Commun.*, 1968-971.

Boeke, S.J., Baumgart, I.R., Van Loon, J.J.A., Van Huis, A., Dicke, M. and Kossou, D.K. (2004). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against *Callosobruchus maculatus*. *J. Stored Prod. Res*. **40**:423–438

Bonsu, K.O. (2002). Yield improvement by transferring heat tolerant genes into a local tomato line 'Power'. *Ghana Journal of Horticulture*, Vol. **1**, 2002, pp.40-44.

Brown, J.K., Frohlich, D.R. and Rosell, R.C. (1995). The sweet potato or Silverleaf whiteflies: Biotypes of *Bemisia tabac*i or species complex? *Annu. Rev. Entomol*. **40**:511-534.

Butterworth, J.H. and Morgan, E. D. (1968). Isolation of substance that suppresses feeding in locusts. *J. Chem. Commun*., 23-24.

Chapman, R.F. (1998). The Insects Structure and Function. Cambridge University Press, Cambridge, UK, pp. 770.

Childs, F.J., Chamberlain, J.R., Antwi, E.A., Daniel, J. and Harris P.J.C. (2001). Improvement of Neem and its Potential Benefits to Poor Farmers. For Forestry Research Programme, Renewable Natural Resources Knowledge Strategy, Department for International Development **.** 2001 HDRA Publications, pp. 9-20.

Dimetry, N.Z., Gomaa, A.A., Salem, A.A. and Adbul-El-Moniem, A.S.H. (1996). Bioactivity of some formulations of neem seed kernel extracts against the whitefly *Bemisia tabaci* (GENN.), *Anzeiger fur Scadlingskunde, Pflanzenschutz, Umweltschutz* **69**, 140-141.

Dorn, A. (1986). Effects of azadirachtin on reproductive system and egg development of the heteropteran *Oncopeltus fasciatus* Dallas. Z. Angew. *Entomol.* **102**, 313-319.

Dorn, A., Rademacher, J. M. and Sehn, E. (1987). Effects of azadirachtin on reproductive organs and fertility in the large milkweed bug, *Oncopeltus fasciatus*. In: Schmutterer, H. Ascher, K. R. S. (eds.). *Natural Pesticides from the Neem Tree* (*Azadirachta indica*) *and other Tropical Plants*. *Proc. 3rd Int. Neem Conf*., Nairobi, Kenya, pp. 273-288.

Encyclopaedia Britannica, (2010). Systemic insecticides. Britannica Online Encyclopaedia.http://www.britannica.com/EBchecked/topic/289077/insecticide. Visited on 18th April, 2009.

FAO, (2000). Inter-Country Programme for the Development and Application of Integrated Pest Management in Vegetable Growing in South and South-East Asia. 2000. *Cabbage Integrated Pest Management: An Ecological Guide.* Vientiane, Lao PDR, pp. 229-231.

Fishwick, R.W. (1970). Sahel and Sudan zone of Northern Nigeria, North Cameroon and Sudan. In: Kual, N.R. ed., *Monographiae Biologicae* **20**, pp.59-85.

George, R.A.T. (1985). Vegetable Seed Production. Longman Group UK Limited. pp 209 223.

Gilbertson, R.L. (2008). UC IPM Pest Management Guidelines: Tomato. *UC ANR Publication 3470 Diseases*, pp. 1-2.

Gill, J. S. and Lewis, C. T. (1971). Systemic action of an insect feeding deterrent. *Nature* **232** pp 402-403.

Griffiths, D. C.,Greenway, A. R. and Lioyd, S. L. (1978). The influence of repellent materials and aphid extracts on settling behavior and larviposition of *Myzus piersicae* (Sulzer) (Hemiptera: Aphididae). *Bull. Ent. Res*. **68, pp**. 613-619.

Haskell, P.T. and Schoonhoven, L.M. (1969). The function of certain mouthpart receptors in relation to feeding in *Schistocerca gregaria* and *Locusta migratoria migratotoides*. *Entomologia Experimentalis et applicata* **12**, 423-440.

Hedge, N.G. (1993). Neem production and development, constraints at grassroot level. *Proceedings of the World Neem Conference*, Bangalore, India, pp.1-7.

Heyde, V.D.J., Schmutterer, H. and Saxena, R. C. (1983). Morphogenetic effects of some partially-purified fractions and methanolic extracts of neem seeds on *Mythimna separata* (Walker) and *Ccaphalocrotrocis medinalis* (Guenenee). *Z. Angew. Entomol*. **95**, 230-237.

Hori, M., Hiruma, K. and Riddiford, L.M. (1984). Cultivar melanization in the tobacco hornworm larva. *Insect Biochemistry* **4**, 267-74.

Horna, D., Melinda, S. and Falck-Zepeda, J. (2006) Assessing the Potential Economic Impact of Genetically Modified Crops in Ghana: Tomato, Garden Egg, Cabbage and Cassava. *PBS report*, October 2006, Brief No.**1– 2**

Horna, D., Smale M. and Falck-Zepeda, J. (2008). Assessing the potential economic impact of genetically modified crops in Ghana: Tomato, Garden Egg, Cabbage and Cassava. *PBS report*, pp. 3-20.

Hydra, (1998). The neem tree. The Organic Organization**,** Ryton Organic Gardens COVENTRY CV8 3LG, United Kingdom, pp. 1-18.

Isman, M. Z. and Port, G. R. (1990). Systemic action of neem seed substances against *Pieris brassicae*. *Entomol. exp. appl*. **54**: 297-300.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology,* 2006. **51**:45–66.

Kao, C. H. and Cheng, E.Y. (2001). Insecticide Resistance in *Plutella xylostella L. XI*.

Karnavar, G.K. (1987). Influence of azadirachtin on insect nutrition and reproduction: *Proceedings of the Indian Academy of Sciences, Animal Sciences* **96**, 341-347.

Koolman, J., Bidmon, H.J., Lehman, M. and Kauser, G. ( 1988). On the mode of action of azadirachtin in blowfly larvae and pupae. In: Endocrinological Frontiers in Physiological Insect Ecology. (Sehnal, F., Zobza, A., Denlinger, D.J. (eds.), Wroclaw Technical University Press, Wroclaw, Poland, pp. 55-67.

Koul, O., Amanai, K. and Ohtaki, T. (1987). Effect of azadirachtin on the endocrine events of *Bombyx mori*. *Journal of Insect Physiology* **33**, 103-108.

Koul, O. and Isman, M. B. (1991). Effects of azadirachtin on the dietary utilization and the development of the variegated cutworm *Performa saucier*. *J. Insect. Physiol*. **37**, 591-598.

Kraus, W., Bokel, M., Klenck, A. and Pohnl, H. (1985). The structure of azadirachtin and 22, 23-dihydro-23β-methoxyazadirachtin. *Tetrahedron Letter* **26**, 6435-6438.

Kumar, J. (1997). Neem oil content and its chemical constituents in relation to the agro-ecological factors and regions in India. *Pesticide Research Journal* **9**, 216-225.

Langewald, J. and Schmutterer, H. (1992). Effects of neem oil treatment on the phase status of desert locust, *Shitocerca gregaria*. In: Biological Control of locusts and Grasshoppers: *Proceedings of a workshop held at the International Institute of Tropical Agriculture,* Cotonou, Republic of Benin, pp. 142-154.

Legg, J., Gerling, D. and Neuenschwander, P. (2003). Biological control of whiteflies in Sub-Saharan Africa. Biological Control in IPM System in Africa. CAB International . Publishing. Wallingford, UK. www.cabi.org. Visited on 18th April, 2009.

Levent, E., Inane, O. and Erdal, N.Y. (2005). Effects of a commercial neem (Neem Azal$^{TM}$ – T/S) on early and late developmental stages of the Beet armyworm, *Spodoptera exiqua* (Hübner) (Lepidoptera: Noctuidae). *Pakistan Journal of Biological Sciences* **8 (4)**: 520 – 526.

Malczewska, W., Gelman, D.B. and Cymborowski, B. (1988). Effects of azadirachtin on development, juvenile hormone and ecdysteroid titres in chilled *Galleria mellonella* larvae. *Journal of Insect Physiology* **34**, 725-732.

Mansour, F.A., Ascher, K.R.S. and Omari, N. (1987). Effects of neem seed kernel extracts from different solvents on the predacious mite *Phytoseilus persimilis* and Phytophagous mite *Tetranychus cinnabarinus*. *Phytoparasitica* **15**, 125-130.

Mansour, F.A., Ascher, K.R.S. and Abo-Moch, F. (1993). Effects of Margosan, Azatin and RD9-Repelin on spiders, and on predacious and phytophagus mites. *Phytoparasitica* **21**, 205-211.

Mansour, F.A., Ascher, K.R.S. and Abo-Moch, F. (1997). Effects of neemguard on Phytophagous predacious mites and on spiders. *Phytoparasitica* **25**, 333-336.

Martin, N.A. (1999). Whitefly Biology, identification and life cycle. *Crop and Food Research, Broadsheet* **No. 91**, February 1999, pp. 1-8.

Mordue, A.J. and Blackwell, A. (1993). Azadirachtin: an update. *Journal of Insect Physiology* **39**, 903-924.

National Research Council, (1992). Neem: *A tree for solving global problems.* National Academy Press. Washington D.C., U.S.A, pp. 141.

Obeng-Ofori, D. and Ankrah, D. A. (2002). Effectiveness of aqueous neem extracts for the control of insect pest on cabbage (*Brassica oleracea* var *capitata* L.) in the Accra plains of Ghana`. *Agricultural and Food Sciences Journal of Ghana* **1** (July): 83-94.

Obeng-Ofori, D., Danquah, E.Y. and Ofosu-Anim, J. (2007). Vegetable and Spice Crop Production in West Africa. City Printers Limited, pp. 53-65.

Ogemah, V.K. (2003). Influence of derivatives of neem tree (*Azadirachta indica* A. JUSS) on the Biology and Behaviour of Prostephanus truncates (HORN) (Coleoptera: Bostrichidae) and its Predator , Teretrius ingrescens (LEWIS) (Coleoptera : Histeridae), *Deutschen Nationalbibliografie*. Berlin, Germany, pp. 20-31.

Owusu-Ansah, F., K. Afreh-Nuamah, Obeng-Ofori, D. and Ofosu-Budu K. G. (2001). Growth promoting properties and yield effects of aqueous neem seed extract, biobit and karate on local garden eggs (*Solanum integrifolium* L.) in the field. *Journal of the Ghana Science Association* **3 (3)**: 136-144.

Panhwar, F. (2005). The Neem Tree (*Azadirachta indica* A. JUSS), A natural practice in Pakistan. *Digitalverlag GmbH*, Germany, pp. 1-9.

Parkman, P. and Pienkowski, R.L. (1990). Sublethal effects of neem seed kernel extracts on adults of *Liriomyza trifolii* (Diptera: Agronyzidae). *Journal of Economic Entomology* **83**, 1246-1249.

Peet, M. (1995). *Sustainable Practices for Vegetable Production in the South*. Focus Publishing, Newburyport, MA 0195, USA.

Perring, T.M. (2001). The *Bemisia tabaci* species complex. *Crop Protection* **20**: 725-737

Rembold, H. and Sieber, K.P. (1981). Inhibition of oogenesis and ovarian ecdysteroid synthesis by azadirachtin in *Locusta migratoria miratoriodes*, *Zeitschrift fur Naturforschung* **36**, 466-469.

Rembold, H. (1995). Growth and metamorphosis. In: Schmutterer, 1995 (ed.). The Neem Tree: Source of Unique Natural Products for Integrated Pest Management, Medicine, Industry and other purposes, VCH. Weinheim, pp. 418-432.

Saxena, R. C. (1989). Insecticides from neem, In J. T. Arnason, B.J.R. Philogene and P. Morand (eds.). Insecticides of plant origin. *ACS Symposium Series* No. **387**. American Chemical Society, Washington, DC. pp. 110-135.

Schluter,U. (1985). Occurrence of weight gain reduction and inhibition of metamorphosis and storage protein formation in the last larval instars of the Mexican bean bettle, *Epilachna vrivestis*, after injection of azadirachtin. *Entomologia Experimentalis Applicata* **39**, 773-777.

Schluter, U. (1987). Effects of azadirachtin on developing tissues of various insect larva. In: Schmutterer, H. and Ascher, K.R.S. (eds.). *Natural Pesticides from the Neem Tree (Azadirachta indica A. JUSS) and other Tropical plants. Proceedings of the 3rd International Neem Conference*, Nairobi, Kenya, pp. 331-348.

Schmutterer, H. and Ascher, K. R. (1987). Natural pesticides from the neem tree and other tropical plants. *Proc. 3rd Int. Neem Conf.*, Nairobi, (1986) Eschborn: GTZ pp. 351-60.

Schmutterer, H. and Wilps, J. (1995). Activity (Fitness, Mobility, Vigour). In: Schmutterer, H 1995 (ed). *The Neem Tree: Source of Unique Natural Products for Integrated Pest Management, Medicine, Industries and other Purposes*. VCH, Weinheim, Germany, pp 418-432.

Schmutterer, H. (1969). Pests of crops in Northeast and Central Africa with particular reference to the Sudan. Gustav. Fischer Verlag. Stuttgart. Portland. U.S.A. pp 10-15

Schmutterer, H. (1987). Fecundity reducing and reducing and sterilizing effects of neem seed kernel extracts in the Colorado potato beetle, *Leptinotarsa decemlineata*.

Schmutterer, H. (1988). Potential of azadirachtin-containing pesticides for integrated pest control in developing and industrialized countries. *J. Insect. Physiol*. **34**: 713-719.

Schmutterer, H. (1990). Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. *Annu. Rev. Entomol*. **35**: 271-297.

Schmutterer, H. (1995). *The neem tree, Azadirachta indica A. Juss and other Meliaceous plants*. Sources of unique natural products for Integrated Pest Management, medicines, industry and other purposes. VCH Publishers Inc., New York, USA, pp.253

Schmutterer, H. (1997). Side effects of neem on pathogens, predators and parasitoids insect pests. *Handout at the 5th Neem Awareness Workshop*, Mbita, Kenya, 15-24, June 1997.

Schmutterer, H. (1998). Origin, geographical distribution and use of neem tree *Azadirachta indica* – a worldwide overview. In: Schmutterer, H.(ed). *The Potentials of the Neem Tree in Ghana. Proceedings of a seminar held in Dodowa*, October 1998, GTZ, Eschborn, Germany. pp 27-33.

Sharafel, D. N. (1986). Investigation into the biology, ecology and control of the cotton aphid in the Sudan. Crop Pest Management in the Sudan; *Proceeding of a symposium held in Khartoum*, Feb. 1986. Min. of Agric. And University of Khartoum, Khartoum Univ. Press, Khartoum pp. 68-71.

Shuaib, M., Khan, S. H. and Mulghani, N. A. G. (2008). Effect of temperature and relative humidity on population dynamics of sucking insect pests of cotton (*Gossypium hirsutum* L.). Endure International Conference 2008: Diversifying crop protection, 12-15 October 2008 La Grande-Motte, France - Oral presentations. pp. 2.

Sontakke,. B.K. and Dash, A.N. (1996). Studies on the effects of insecticides and neem formulation against major insect pests of mustard and their safety to honey bees. *Journal of Environment and Toxicology* **6**, 87-88.

Tanzubil, P.B. and McCaffery, A. R. (1990). Effects of azadirachtin on reproduction in the African armyworm (*Spodoptera exempta*). *Entomologia Experimentalis et Applicata* **57**, 115-121.

Tetteh , F.M. and Glover, M. A (2008). Effect of Pesticide Application Rate on Yield of Vegetables and Soil Microbial Communities. *West African Journal of Applied Ecology*, Vol. **12**, 2008, pp. 1-7.

Tweneboah, C.K. (1998). *Vegetables and Spices in West Africa, with special reference to Ghana.* CO-WOOD Publishers, UK, pp. 63-71.

Vollinger, M. (1987). The possible development of resistance against neem seed kernel extract and deltamethrin in *Plutella xylostella*. In: Schmutterer, H., Ascher, K. R., (eds.). *Natural Pesticides from the Neem Tree and other Tropical Plants. Proc. 3rd Int. Neem Conf.* Nairobi, Kenya, GTZ, Eschborn, Germany, pp. 543-554.

Warthen, J.D. (1989). Neem (azadirachta indica A. JUSS.): Organisms affected and reference list update. *Proceedings of the Entomological Society of Washington* **91**, 367-388.

Warthen, J.D. Jr., Uebel, E.C., Dutky, S. R. and Finegold, W.R. (1978). Adult house fly feeding deterrent from neem seeds. *USDA/SEA Agric. Res. Results*, Northeast. Ser. **2**, 1-11

Weaver, D.K.and Sumbramanyam, B. (2000). Botanicals. In: Sumbramanyam, B. and Hagstrum, D.W. (eds.). *Alternatives to Pesticides in stored products IPM.* Kluwer Academic Publishers, Massachusetts, U.S.A, pp 303-320.

West, A.J. and Mordue, A. J. (1992). The influence of azadirachtin on the feeding behavior of cereal aphids and slugs. *Entomol. exp. appl*. **62**: 75-79.

KNUST

NYANSAPƆ WƆSANE NO BADWENMA

## APPENDICES

**APPENDIX A: Total number of whiteflies at different days for each treatment (Minor Season, 2008)**

| | | TREATMENTS | | | |
|---|---|---|---|---|---|
| **DATES** | **REPLICATIONS** | **CONTROL** | **KARATE** | **ANKPE** | **NKPE** |
| 02.11.08 | 1 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 |
| 09.11.08 | 1 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 |
| 13.11.08 | 1 | 2.0 | 0.0 | 3.0 | 1.0 |
| | 2 | 1.0 | 3.0 | 4.0 | 1.0 |
| | 3 | 2.0 | 2.0 | 3.0 | 2.0 |
| 16.11.08 | 1 | 2.0 | 2.0 | 3.0 | 4.0 |
| | 2 | 3.0 | 0.0 | 4.0 | 1.0 |
| | 3 | 2.0 | 2.0 | 2.0 | 2.0 |
| 19.11.08 | 1 | 1.0 | 6.0 | 5.0 | 3.0 |
| | 2 | 3.0 | 4.0 | 3.0 | 4.0 |
| | 3 | 3.0 | 3.0 | 4.0 | 1.0 |
| 22.11.08 | 1 | 8.0 | 4.0 | 5.0 | 8.0 |
| | 2 | 5.0 | 5.0 | 3.0 | 5.0 |
| | 3 | 6.0 | 4.0 | 7.0 | 3.0 |
| 25.11.08 | 1 | 10.0 | 3.0 | 4.0 | 4.0 |
| | 2 | 7.0 | 2.0 | 2.0 | 2.0 |
| | 3 | 5.0 | 1.0 | 1.0 | 3.0 |
| 28..11.08 | 1 | 55.0 | 18.0 | 24.0 | 26.0 |
| | 2 | 48.0 | 13.0 | 10.0 | 30.0 |
| | 3 | 52.0 | 17.0 | 21.0 | 40.0 |
| 01.12.08 | 1 | 80.0 | 35.0 | 40.0 | 50.0 |
| | 2 | 70.0 | 30.0 | 30.0 | 70.0 |
| | 3 | 80.0 | 20.0 | 26.0 | 40.0 |

| | | | | | |
|---|---|---|---|---|---|
| 04.12.08 | 1 | 60.0 | 20.0 | 30.0 | 40.0 |
| | 2 | 85.0 | 15.0 | 26.0 | 20.0 |
| | 3 | 70.0 | 30.0 | 22.0 | 65.0 |
| 11.12.08 | 1 | 50.0 | 7.0 | 8.0 | 15.0 |
| | 2 | 33.0 | 5.0 | 6.0 | 8.0 |
| | 3 | 70.0 | 3.0 | 4.0 | 12.0 |
| 18.12.08 | 1 | 75.0 | 8.0 | 20.0 | 30.0 |
| | 2 | 80.0 | 7.0 | 15.0 | 20.0 |
| | 3 | 30.0 | 5.0 | 30.0 | 25.0 |
| 25.12.09 | 1 | 60.0 | 4.0 | 15.0 | 20.0 |
| | 2 | 70.0 | 8.0 | 15.0 | 30.0 |
| | 3 | 45.0 | 5.0 | 10.0 | 15.0 |
| **TOTAL** | | **1163.0** | **291.0** | **405.0** | **600.0** |

KNUST
NYANSAPↃ WↃ SANE NO BADWENMA

**APPENDIX B: Total number of whiteflies at different days for each treatment (Major Season, 2009)**

| | | TREATMENTS | | | |
|---|---|---|---|---|---|
| DATES | REPLICATIONS | CONTROL | KARATE | ANKPE | NKPE |
| 22.06.09 | 1 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 |
| 29.06.09 | 1 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 |
| 3.07.09 | 1 | 2 | 5 | 3 | 2 |
| | 2 | 4 | 3 | 5 | 2 |
| | 3 | 3 | 3 | 4 | 3 |
| 6.07.09 | 1 | 6 | 6 | 4 | 8 |
| | 2 | 5 | 5 | 8 | 7 |
| | 3 | 5 | 6 | 8 | 7 |
| 9.07.09 | 1 | 10 | 0 | 3 | 5 |
| | 2 | 9 | 1 | 6 | 8 |
| | 3 | 15 | 2 | 5 | 3 |
| 12.07.09 | 1 | 15 | 1 | 5 | 5 |
| | 2 | 18 | 2 | 8 | 15 |
| | 3 | 18 | 1 | 3 | 13 |
| 15.07.09 | 1 | 10 | 4 | 5 | 8 |
| | 2 | 14 | 3 | 6 | 8 |
| | 3 | 10 | 4 | 5 | 15 |
| 18.07.09 | 1 | 25 | 5 | 15 | 15 |
| | 2 | 24 | 6 | 15 | 18 |
| | 3 | 25 | 5 | 10 | 18 |
| 21.07.09 | 1 | 30 | 6 | 18 | 2 |
| | 2 | 25 | 4 | 20 | 15 |
| | 3 | 30 | 6 | 15 | 20 |
| 24.07.09 | 1 | 8 | 5 | 6 | 10 |

| | | | | | |
|---|---|---|---|---|---|
| | 2 | 15 | 4 | 8 | 10 |
| | 3 | 15 | 5 | 8 | 8 |
| 27.07.09 | 1 | 13 | 4 | 10 | 8 |
| | 2 | 18 | 3 | 6 | 12 |
| | 3 | 20 | 3 | 9 | 6 |
| 3.08.09 | 1 | 45 | 8 | 20 | 25 |
| | 2 | 35 | 6 | 24 | 20 |
| | 3 | 40 | 8 | 20 | 28 |
| 10.08.09 | 1 | 20 | 2 | 8 | 10 |
| | 2 | 18 | 2 | 5 | 8 |
| | 3 | 15 | 3 | 6 | 10 |
| **TOTAL** | | **565.0** | **130.0** | **301.0** | **352.0** |

KNUST

**APPENDIX C: Total number of leaves damaged by *B. tabaci* on each treatment (Minor season 2008)**

| | | TREATMENTS | | | |
|---|---|---|---|---|---|
| **DATES** | **REPLICATIONS** | **CONTROL** | **KARATE** | **ANKPE** | **NKPE** |
| 01.12.08 | 1 | 5 | 0 | 2 | 2 |
| | 2 | 3 | 2 | 1 | 0 |
| | 3 | 4 | 0 | 1 | 1 |
| 4.12.08 | 1 | 5.0 | 0.0 | 2.0 | 3.0 |
| | 2 | 8.0 | 0.0 | 3.0 | 5.0 |
| | 3 | 4.0 | 0.0 | 1.0 | 0.0 |
| 11.12.08 | 1 | 10.0 | 1.0 | 2.0 | 8.0 |
| | 2 | 8.0 | 0.0 | 3.0 | 6.0 |
| | 3 | 8.0 | 2.0 | 6.0 | 2.0 |
| 18.12.08 | 1 | 11.0 | 1.0 | 3.0 | 6.0 |
| | 2 | 3.0 | 0.0 | 4.0 | 4.0 |
| | 3 | 6.0 | 0.0 | 2.0 | 3.0 |
| **TOTAL** | | **75** | **6** | **30** | **37** |

KNUST

**APPENDIX D: Total number of plants infested with tomato yellow leave curl virus (TYLCV) for each treatment (Minor Season 2008)**

| | | TREATMENTS | | | |
|---|---|---|---|---|---|
| **DATES** | **REPLICATIONS** | **CONTROL** | **KARATE** | **ANKPE** | **NKPE** |
| 8.12.08 | 1 | 1 | 0 | 0 | 0 |
| | 2 | 4 | 0 | 1 | 2 |
| | 3 | 1 | 0 | 0 | 0 |
| 11.12.08 | 1 | 1 | 0 | 0 | 0 |
| | 2 | 2 | 0 | 1 | 2 |
| | 3 | 1 | 0 | 0 | 0 |
| 18.12.08 | 1 | 7 | 0 | 0 | 4 |
| | 2 | 3 | 0 | 0 | 0 |
| | 3 | 2 | 0 | 1 | 1 |
| 21.12.08 | 1 | 3 | 0 | 0 | 1 |
| | 2 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 |
| **TOTAL** | | **25** | **0** | **3** | **10** |

KNUST
NYANSAPƆ WƆSANE NO BADWENMA

**APPENDIX E: Total yield of tomato (kg) at different days for each treatment (Minor Season 2008)**

| | | TREATMENTS | | | |
|---|---|---|---|---|---|
| **DATES** | **REPLICATES** | **CONTROL** | **KARATE** | **ANKPE** | **NKPE** |
| 12.01.09 | 1 | 0.10 | 0.15 | 0.15 | 0.00 |
| | 2 | 0.15 | 0.25 | 0.00 | 0.16 |
| | 3 | 0.10 | 0.10 | 0.05 | 0.05 |
| 16.01.09 | 1 | 0.14 | 0.25 | 0.15 | 0.10 |
| | 2 | 0.15 | 0.14 | 0.20 | 0.14 |
| | 3 | 0.10 | 0.20 | 0.30 | 0.15 |
| 20.01.09 | 1 | 0.18 | 0.20 | 0.20 | 0.30 |
| | 2 | 0.10 | 0.29 | 0.10 | 0.20 |
| | 3 | 0.30 | 0.20 | 0.40 | 0.10 |
| 24.01.09 | 1 | 0.15 | 0.38 | 0.30 | 0.20 |
| | 2 | 0.30 | 0.20 | 0.20 | 0.19 |
| | 3 | 0.20 | 0.30 | 0.30 | 0.30 |
| 28.01.09 | 1 | 1.05 | 2.43 | 2.27 | 0.78 |
| | 2 | 1.04 | 2.18 | 0.65 | 0.50 |
| | 3 | 0.70 | 1.09 | 0.75 | 0.30 |
| 01.02.09 | 1 | 0.72 | 1.65 | 1.27 | 1.03 |
| | 2 | 0.83 | 1.32 | 0.79 | 0.92 |
| | 3 | 0.50 | 1.15 | 0.88 | 0.78 |
| **TOTAL** | | **6.8** | **12.5** | **9.0** | **6.2** |

**APPENDIX F: Total yield of tomato (kg) at different days for each treatment (Major season 2009)**

| | | TREATMENTS | | | |
|---|---|---|---|---|---|
| **DATES** | **REPLICATIONS** | **CONTROL** | **KARATE** | **ANKPE** | **NKPE** |
| 29.09.09 | 1 | 0.14 | 0.15 | 0.11 | 0.23 |
| | 2 | 0.17 | 0.10 | 0.08 | 0.27 |
| | 3 | 0.10 | 0.20 | 0.10 | 0.15 |
| 3.10.09 | 1 | 0.49 | 0.50 | 0.63 | 0.45 |
| | 2 | 0.60 | 0.40 | 0.45 | 0.50 |
| | 3 | 0.40 | 0.32 | 0.65 | 0.34 |
| 7.10.09 | 1 | 0.75 | 0.80 | 0.75 | 0.90 |
| | 2 | 0.98 | 1.02 | 1.07 | 1.07 |
| | 3 | 0.72 | 0.76 | 0.88 | 0.93 |
| 11.10.09 | 1 | 2.58 | 1.02 | 2.08 | 1.92 |
| | 2 | 2.05 | 3.03 | 2.50 | 2.06 |
| | 3 | 1.42 | 2.95 | 1.77 | 2.67 |
| 15.10.09 | 1 | 1.57 | 1.05 | 2.00 | 1.35 |
| | 2 | 1.63 | 2.25 | 2.50 | 2.00 |
| | 3 | 1.71 | 2.20 | 1.50 | 2.30 |
| **TOTAL** | | **15.3** | **16.8** | **17.1** | **17.2** |

**APPENDIX G: Analysis of variance (ANOVA) for number of whiteflies (Minor season 2008) using Student-Newman-Keuls Test, 2003 edition.**

| TREATMENTS | NUMBER OF OBSERVATIONS | MEAN | STANDARD ERROR | SNK GROUPING |
|---|---|---|---|---|
| **CONTROL** | 3 | 391.00 | 13.01 | A |
| **NKPE** | 3 | 200.00 | 4.93 | B |
| **ANKPE** | 3 | 135.00 | 11.53 | C |
| **KARATE** | 3 | 97.00 | 5.00 | D |
| | | | | |
| **F-value** | **P-value** | | | |
| 194.06 | <0.0001 | | | |

Within the columns, means with the same letter are not significantly different at $P \leq 0.05$

KNUST

**APPENDIX H: Analysis of variance (ANOVA) for insect number (Major season 2009) using Student-Newman-Keuls Test, 2003 edition.**

| TREATMENTS | NUMBER OF OBSERVATIONS | MEAN | STANDARD ERROR | SNK GROUPING |
|---|---|---|---|---|
| **CONTROL** | 3 | 188.33 | 3.34 | A |
| **NKPE** | 3 | 117.33 | 9.94 | B |
| **ANKPE** | 3 | 100.33 | 5.46 | B |
| **KARATE** | 3 | 43.33 | 2.19 | C |
| | | | | |
| **F-value** | **P-value** | | | |
| 96.38 | <0.0001 | | | |

Within the columns, means with the same letter are not significantly different at $P \leq 0.05$

KNUST

**APPENDIX I: Analysis of variance (ANOVA) for number of damaged leaves (Minor season 2008) using Student-Newman-Keuls Test, 2003 edition.**

| TREATMENTS | NUMBER OF OBSERVATIONS | MEAN | STANDARD ERROR | SNK GROUPING |
|---|---|---|---|---|
| **CONTROL** | 3 | 25.00 | 3.00 | A |
| **NKPE** | 3 | 13.33 | 3.84 | B |
| **ANKPE** | 3 | 10.00 | 0.58 | B |
| **KARATE** | 3 | 2.00 | 0.00 | C |
| | | | | |
| **F-value** | **P-value** | | | |
| 27.92 | <0.0001 | | | |

Within the columns, means with the same letter are not significantly different at P ≤ 0.05

KNUST

**APPENDIX J: Analysis of variance (ANOVA) for number of infested plants (Minor season 2008) using Student-Newman-Keuls Test, 2003 edition.**

| TREATMENTS | NUMBER OF OBSERVATIONS | MEAN | STANDARD ERROR | SNK GROUPING |
|---|---|---|---|---|
| **CONTROL** | 3 | 7.00 | 2.31 | A |
| **NKPE** | 3 | 2.67 | 1.20 | AB |
| **ANKPE** | 3 | 0.67 | 0.33 | BC |
| **KARATE** | 3 | 0.00 | 0.00 | C |
| | | | | |
| **F-value** | **P-value** | | | |
| 11.54 | <0.0028 | | | |

Within the columns, means with the same letter are not significantly different at P ≤ 0.05

KNUST

**APPENDIX K: Analysis of variance (ANOVA) for yield of tomato (Minor season 2008) using Student-Newman-Keuls Test, 2003 edition.**

| TREATMENTS | NUMBER OF OBSERVATIONS | MEAN | STANDARD ERROR | SNK GROUPING |
|---|---|---|---|---|
| **KARATE** | 3 | 3.17 | 0.46 | A |
| **ANKPE** | 3 | 2.65 | 0.44 | A |
| **NKPE** | 3 | 2.06 | 0.22 | A |
| **CONTROL** | 3 | 1.83 | 0.12 | A |
| | | | | |
| **F-value** | **P-value** | | | |
| 3.11 | <0.0887 | | | |

Within the columns, means with the same letter are not significantly different at $P \leq 0.05$

KNUST

**APPENDIX L: Analysis of variance (ANOVA) for yield of tomato (Major season 2009) using Student-Newman-Keuls Test, 2003 edition.**

| TREATMENTS | NUMBER OF OBSERVATIONS | MEAN | STANDARD ERROR | SNK GROUPING |
|---|---|---|---|---|
| **NKPE** | 3 | 5.71 | 0.45 | A |
| **ANKPE** | 3 | 5.69 | 0.49 | A |
| **KARATE** | 3 | 5.58 | 1.04 | A |
| **CONTROL** | 3 | 5.10 | 0.37 | A |
| | | | | |
| **F-value** | **P-value** | | | |
| 0.19 | <.0.897 | | | |

Within the columns, means with the same letter are not significantly different at $P \leq 0.05$

KNUST

**Appendix M:** **GHANA METEOROLOGICAL AGENCY**

**AGROMETEOROLOGICAL DIVISION**

**Station:** K.N.U.S.T - Kumasi **Station Number:** 0601-050-17

**Longitude:** $01^{0}$ 33' West **Latitude:** $06^{0}$41'N **Altitude:** 261.4

**Month:** October **Year:** 2008 **Time:** 0900 HOURS

| **DATE** | **TEMPERATURE** | | **RELATIVE HUMIDITY (%)** | **RAINFALL (mm)** |
|---|---|---|---|---|
| | **MAX ($^{0}$C)** | **MIN ($^{0}$C)** | | |
| 1 | 31.0 | 21.2 | 95 | 5.9 |
| 2 | 31.5 | 21.5 | 91 | 0.0 |
| 3 | 30.5 | 21.5 | 81 | 0.0 |
| 4 | 32.0 | 22.5 | 88 | 0.0 |
| 5 | 31.0 | 21.5 | 81 | 16.5 |
| 6 | 31.0 | 21.5 | 80 | 9.2 |
| 7 | 31.0 | 22.2 | 84 | 0.0 |
| 8 | 30.5 | 21.5 | 92 | 0.0 |
| 9 | 30.0 | 21.6 | 84 | 0.0 |
| 10 | 30.8 | 21.5 | 84 | 0.0 |
| 11 | 31.0 | 21.5 | 88 | 32.5 |
| 12 | 30.5 | 20.5 | 86 | 0.0 |
| 13 | 31.0 | 21.5 | 88 | 4.1 |
| 14 | 31.0 | 21.5 | 88 | 0.0 |
| 15 | 30.8 | 21.2 | 77 | 0.5 |
| 16 | 31.0 | 21.5 | 80 | 5.5 |
| 17 | 31.5 | 21.5 | 91 | 0.0 |
| 18 | 31.5 | 21.5 | 80 | 1.6 |
| 19 | 31.0 | 22.0 | 91 | 4.2 |
| 20 | 30.8 | 20.5 | 87 | 0.0 |

| | | | | |
|---|---|---|---|---|
| 21 | 31.5 | 22.5 | 82 | 5.3 |
| 22 | 32.0 | 22.5 | 82 | 0.0 |
| 23 | 32.0 | 21.5 | 87 | 0.0 |
| 24 | 32.0 | 22.0 | 86 | 0.0 |
| 25 | 32.0 | 22.5 | 82 | 0.0 |
| 26 | 32.0 | 22.5 | 84 | 3.4 |
| 27 | 32.5 | 21.0 | 78 | 5.9 |
| 28 | 32.0 | 21.2 | 78 | 0.0 |
| 29 | 32.0 | 22.5 | 78 | 0.0 |
| 30 | 31.5 | 22.0 | 83 | 0.0 |
| 31 | 32.0 | 22.0 | 92 | 1.2 |
| **Total** | 970.9 | 671.9 | 2,630 | 95.8 |
| **Mean** | 31.3 | 21.6 | 85 | 3.1 |

**Appendix N:** **GHANA METEOROLOGICAL AGENCY**

**AGROMETEOROLOGICAL DIVISION**

**Station:** K.N.U.S.T - Kumasi **Station Number:** 0601-050-17

**Longitude:** $01^0$ 33' West **Latitude:** $06^0$41'N **Altitude:** 261.4

**Month:** November **Year:** 2008 **Time:** 0900 HOURS

| DATE | TEMPERATURE | | RELATIVE HUMIDITY (%) | RAINFALL (mm) |
|---|---|---|---|---|
| | MAX ($^0$C) | MIN ($^0$C) | | |
| 1 | 32.5 | 22.0 | 94 | 0.0 |
| 2 | 31.5 | 22.5 | 86 | 5.8 |
| 3 | 31.8 | 22.2 | 85 | 0.0 |
| 4 | 32.5 | 21.8 | 80 | 4.5 |
| 5 | 32.5 | 22.5 | 80 | 0.0 |
| 6 | 32.5 | 22.5 | 77 | 0.0 |
| 7 | 32.0 | 21.5 | 87 | 0.0 |
| 8 | 32.0 | 21.2 | 94 | 0.0 |
| 9 | 33.0 | 22.5 | 82 | 0.0 |
| 10 | 32.5 | 22.0 | 82 | 0.0 |
| 11 | 32.5 | 21.5 | 81 | 0.0 |
| 12 | 32.5 | 22.0 | 77 | 0.0 |
| 13 | 32.5 | 22.0 | 85 | 0.0 |
| 14 | 33.0 | 21.5 | 84 | 0.0 |
| 15 | 33.0 | 22.0 | 87 | 0.0 |
| 16 | 33.5 | 22.0 | 84 | 0.0 |
| 17 | 33.5 | 22.0 | 79 | 0.0 |
| 18 | 33.0 | 22.5 | 82 | 10.8 |

| | | | | |
|---|---|---|---|---|
| 19 | 33.0 | 22.5 | 81 | 0.0 |
| 20 | 32.5 | 22.5 | 86 | 1.8 |
| 21 | 32.5 | 22.5 | 82 | 0.0 |
| 22 | 33.0 | 22.5 | 84 | 0.0 |
| 23 | 33.0 | 22.5 | 84 | 0.0 |
| 24 | 33.0 | 23.0 | 84 | 0.0 |
| 25 | 33.0 | 23.0 | 84 | 7.8 |
| 26 | 33.0 | 21.2 | 92 | 0.0 |
| 27 | 32.0 | 21.0 | 92 | 0.0 |
| 28 | 33.0 | 23.0 | 86 | 0.0 |
| 29 | 33.5 | 23.0 | 83 | 0.0 |
| 30 | 33.0 | 23.0 | 82 | 0.0 |
| 31 | | | | |
| **Total** | 980.8 | 665.9 | 692.0 | 30.7 |
| **Mean** | 32.7 | 22.2 | 23.0 | 1.0 |

KNUST

**Appendix O: GHANA METEOROLOGICAL AGENCY**

**AGROMETEOROLOGICAL DIVISION**

**Station:** K.N.U.S.T - Kumasi **Station Number:** 0601-050-17

**Longitude:** $01^0$ 33' West **Latitude:** $06^0$41'N **Altitude:** 261.4

**Month:** December **Year:** 2008 **Time:** 0900 HOURS

| DATE | TEMPERATURE | | RELATIVE HUMIDITY (%) | RAINFALL (mm) |
|---|---|---|---|---|
| | MAX ($^0$C) | MIN ($^0$C) | | |
| 1 | 33.0 | 23.0 | 81 | 0.0 |
| 2 | 33.8 | 23.0 | 80 | 9.0 |
| 3 | 33.5 | 21.0 | 79 | 5.2 |
| 4 | 32.5 | 21.5 | 84 | 0.0 |
| 5 | 31.0 | 21.5 | 88 | 0.0 |
| 6 | 33.0 | 14.5 | 45 | 0.0 |
| 7 | 33.0 | 15.0 | 95 | 0.0 |
| 8 | 33.0 | 19.0 | 73 | 0.0 |
| 9 | 33.0 | 21.5 | 81 | 0.0 |
| 10 | 33.0 | 21.5 | 86 | 0.0 |
| 11 | 33.5 | 22.0 | 88 | 0.0 |
| 12 | 33.0 | 21.2 | 80 | 1.1 |
| 13 | 32.0 | 20.0 | 82 | 0.0 |
| 14 | 32.5 | 21.2 | 88 | 0.0 |
| 15 | 32.5 | 21.5 | 87 | 0.0 |
| 16 | 32.5 | 22.5 | 84 | 32.2 |
| 17 | 32.5 | 21.0 | 85 | 0.0 |
| 18 | 32.5 | 21.5 | 87 | 0.0 |

| | | | | |
|---|---|---|---|---|
| 19 | 32.5 | 23.0 | 89 | 0.0 |
| 20 | 32.0 | 21.5 | 92 | 0.0 |
| 21 | 32.5 | 22.5 | 86 | 0.0 |
| 22 | 32.5 | 22.5 | 84 | 0.0 |
| 23 | 32.5 | 22.5 | 84 | 0.0 |
| 24 | 33.0 | 22.0 | 89 | 0.0 |
| 25 | 32.0 | 21.5 | 92 | 0.0 |
| 26 | 32.0 | 20.5 | 86 | 0.0 |
| 27 | 32.0 | 20.6 | 84 | 0.0 |
| 28 | 32.0 | 20.5 | 88 | 0.0 |
| 29 | 33.5 | 21.5 | 88 | 0.0 |
| 30 | 33.0 | 21.5 | 84 | 0.0 |
| 31 | 33.0 | 22.5 | 87 | 0.0 |
| **Total** | 1,012.0 | 655.0 | 2,606 | 47.5 |
| **Mean** | 32.6 | 21.1 | 84 | 1.5 |

KNUST

**Appendix P:** **GHANA METEOROLOGICAL AGENCY**

**AGROMETEOROLOGICAL DIVISION**

**Station:** K.N.U.S.T - Kumasi **Station Number:** 0601-050-17

**Longitude:** $01^0$ 33' West **Latitude:** $06^0$41'N **Altitude:** 261.4

**Month:** June **Year:** 2009 **Time:** 0900 HOURS

| **DATE** | **TEMPERATURE** | | **RELATIVE HUMIDITY (%)** | **RAINFALL (mm)** |
|---|---|---|---|---|
| | **MAX ($^0$C)** | **MIN ($^0$C)** | | |
| 1 | 33.5 | 23.6 | 77 | 0.0 |
| 2 | 33.5 | 23.6 | 86 | 0.0 |
| 3 | 33.5 | 24.1 | 82 | 0.0 |
| 4 | 34.0 | 23.6 | 81 | 0.0 |
| 5 | 33.0 | 22.2 | 82 | 26.3 |
| 6 | 33.5 | 20.9 | 84 | 0.0 |
| 7 | 33.5 | 22.6 | 85 | 3.0 |
| 8 | 33.0 | 23.6 | 89 | 9.1 |
| 9 | 32.5 | 23.6 | 84 | 23.3 |
| 10 | 32.5 | 20.9 | 86 | 6.0 |
| 11 | 33.0 | 23.1 | 88 | 105.4 |
| 12 | 31.5 | 21.6 | 88 | 0.0 |
| 13 | 31.0 | 21.7 | 88 | 8.4 |
| 14 | 31.0 | 22.2 | 86 | 0.0 |
| 15 | 31.5 | 22.1 | 90 | 43.3 |
| 16 | 31.0 | 19.6 | 94 | 2.2 |
| 17 | 31.5 | 20.6 | 89 | 0.0 |
| 18 | 31.5 | 21.2 | 84 | 28.3 |

| | | | | |
|---|---|---|---|---|
| 19 | 31.8 | 21.6 | 90 | 19.7 |
| 20 | 31.5 | 21.8 | 88 | 0.0 |
| 21 | 30.8 | 22.7 | 84 | 5.2 |
| 22 | 30.8 | 21.6 | 93 | 0.0 |
| 23 | 31.8 | 22.2 | 85 | 0.0 |
| 24 | 31.5 | 23.2 | 88 | 0.0 |
| 25 | 29.5 | 22.1 | 86 | 49.6 |
| 26 | 30.5 | 21.7 | 85 | 19.4 |
| 27 | 30.5 | 20.8 | 90 | 1.8 |
| 28 | 29.5 | 22.2 | 92 | 2.5 |
| 29 | 28.0 | 20.0 | 89 | 0.0 |
| 30 | 30.0 | 22.2 | 87 | 14.4 |
| 31 | | | | |
| **Total** | 950.7 | 662.4 | 2,600 | 367.9 |
| **Mean** | 31.7 | 22.1 | 87 | 12.3 |

KNUST
NYANSAPO WO SANE NO BADWENMA

**Appendix Q:** **GHANA METEOROLOGICAL AGENCY**

**AGROMETEOROLOGICAL DIVISION**

**Station:** K.N.U.S.T - Kumasi **Station Number:** 0601-050-17

**Longitude:** $01^0$ 33' West **Latitude:** $06^0$41'N **Altitude:** 261.4

**Month:** July **Year:** 2009 **Time:** 0900 HOURS

| **DATE** | **TEMPERATURE** | | **RELATIVE HUMIDITY (%)** | **RAINFALL (mm)** |
|---|---|---|---|---|
| | **MAX ($^0$C)** | **MIN ($^0$C)** | | |
| 1 | 30.5 | 20.6 | 96 | 0.0 |
| 2 | 30.5 | 22.8 | 84 | 0.0 |
| 3 | 30.5 | 22.6 | 88 | 25.6 |
| 4 | 30.5 | 20.6 | 83 | 43.5 |
| 5 | 30.5 | 20.6 | 87 | 7.3 |
| 6 | 30.8 | 20.6 | 88 | 55.7 |
| 7 | 31.0 | 20.7 | 95 | 1.5 |
| 8 | 30.8 | 21.6 | 83 | 29.8 |
| 9 | 30.5 | 21.2 | 94 | 28.1 |
| 10 | 28.5 | 21.6 | 89 | 9.5 |
| 11 | 29.0 | 19.6 | 95 | 0.0 |
| 12 | 28.0 | 20.8 | 87 | 0.0 |
| 13 | 28.0 | 21.5 | 86 | 0.0 |
| 14 | 28.0 | 20.6 | 91 | 0.0 |
| 15 | 30.5 | 21.8 | 85 | 0.0 |
| 16 | 30.5 | 21.6 | 85 | 0.0 |
| 17 | 29.9 | 22.0 | 91 | 0.0 |
| 18 | 30.0 | 22.2 | 91 | 0.0 |
| 19 | 29.5 | 22.0 | 87 | 0.0 |
| 20 | 29.5 | 21.6 | 85 | 0.0 |

| | | | | |
|---|---|---|---|---|
| 21 | 30.0 | 21.6 | 86 | 1.0 |
| 22 | 30.0 | 22.2 | 89 | 3.1 |
| 23 | 29.5 | 21.7 | 87 | 0.0 |
| 24 | 30.8 | 21.6 | 86 | 0.0 |
| 25 | 30.5 | 21.7 | 87 | 0.0 |
| 26 | 28.5 | 21.2 | 86 | 0.0 |
| 27 | 28.5 | 21.2 | 83 | 0.0 |
| 28 | 28.0 | 21.2 | 90 | 0.0 |
| 29 | 28.0 | 21.2 | 87 | 0.0 |
| 30 | 28.0 | 21.2 | 87 | 0.0 |
| 31 | 28.5 | 21.6 | 89 | 0.0 |
| **Total** | 917.3 | 663.0 | 2,727 | 21.0 |
| **Mean** | 29.6 | 21.4 | 88 | 0.6 |

KNUST

**Appendix R:** **GHANA METEOROLOGICAL AGENCY**

**AGROMETEOROLOGICAL DIVISION**

**Station:** K.N.U.S.T - Kumasi **Station Number:** 0601-050-17

**Longitude:** $01^0$ 33' West **Latitude:** $06^0$41'N **Altitude:** 261.4

**Month:** August **Year:** 2009 **Time:** 0900 HOURS

| **DATE** | **TEMPERATURE** | | **RELATIVE HUMIDITY (%)** | **RAINFALL (mm)** |
|---|---|---|---|---|
| | **MAX ($^0$C)** | **MIN ($^0$C)** | | |
| 1 | 28.0 | 21.6 | 89 | 2.8 |
| 2 | 28.0 | 21.8 | 89 | 0.0 |
| 3 | 27.5 | 21.6 | 87 | 0.0 |
| 4 | 27.5 | 21.2 | 92 | 0.0 |
| 5 | 28.0 | 22.2 | 87 | 0.0 |
| 6 | 28.0 | 22.0 | 89 | 0.8 |
| 7 | 28.0 | 22.0 | 94 | 0.0 |
| 8 | 27.5 | 22.2 | 94 | 0.0 |
| 9 | 27.5 | 21.6 | 95 | 0.0 |
| 10 | 29.0 | 21.6 | 81 | 0.0 |
| 11 | 29.8 | 22.2 | 87 | 0.0 |
| 12 | 28.0 | 21.8 | 95 | 0.0 |
| 13 | 28.5 | 21.6 | 91 | 2.1 |
| 14 | 28.5 | 21.8 | 91 | 0.0 |
| 15 | 28.5 | 21.6 | 87 | 0.0 |
| 16 | 29.0 | 21.8 | 84 | 6.5 |
| 17 | 29.0 | 20.0 | 96 | 0.0 |
| 18 | 29.0 | 21.2 | 93 | 1.4 |

| | | | | |
|---|---|---|---|---|
| 19 | 29.0 | 21.6 | 98 | 5.4 |
| 20 | 29.0 | 21.6 | 91 | 0.0 |
| 21 | 29.0 | 21.8 | 91 | 0.0 |
| 22 | 30.0 | 21.6 | 83 | 0.0 |
| 23 | 30.0 | 21.7 | 88 | 0.0 |
| 24 | 29.5 | 21.8 | 94 | 0.0 |
| 25 | 28.5 | 21.6 | 93 | 0.0 |
| 26 | 29.5 | 21.7 | 85 | 0.0 |
| 27 | 29.5 | 22.2 | 87 | 0.0 |
| 28 | 28.5 | 21.5 | 86 | 0.0 |
| 29 | 28.5 | 21.8 | 91 | 0.0 |
| 30 | 29.0 | 21.7 | 92 | 0.0 |
| 31 | 28.5 | 21.6 | 85 | 0.0 |
| **Total** | 887.8 | 672.0 | 2,785 | 19.0 |
| **Mean** | 28.6 | 21.7 | 90 | 6.8 |

KNUST