EVALUATION OF BIOPESTICIDES IN CONTROL OF RED SPIDER MITES (*Tetranychus evansi*) ON TOMATOES (*Lycopersicum esculentum*)

BY

GRACE GLADYS KITHUSI

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DECLARATION

DECLARATION BY THE CANDIDATE

This thesis is my original work and has not been presented for a degree in any other university.

Name: Grace Gladys Kithusi

Date..18/1/05..Signature.....

DECLARATION BY SUPERVISORS

We confirm that the candidate under my supervision carried out the work in this thesis and I have read and approved it for examination.

1. Dr. S. I. Shibairo

   Date..Jan 6, 2005..Signature.....

2. Dr. M. Knapp

   Date.....Signature.....

   DEPT OF CROP SCIENCE
   FACULTY OF AGRICULTURE
   UNIVERSITY OF NAIROBI
   P.O. Box 30197
   NAIROBI

3. Dr. J. H. Nderitu

   Date..26/1/2005..Signature.....

4. Dr. K. Njoroge

   Date..26/1/05..Signature.....

DEDICATION

This work is dedicated to my husband, sons and my dear parents.

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ABSTRACT

Three neem-based biopesticides, namely Achook (0.15% Azadirachtin), Neemroc (0.03% Azadirachtin + 32% neem oil) and Neem + Corn (0.03% Azadirachtin + 32% corn oil) and one garlic-based product, namely GC- mite (40% garlic extract), were evaluated under laboratory, greenhouse and field conditions for their efficacy against red spider mites (*Tetranychus evansi* Baker and Pritchard) on tomatoes (*Lycopersicum esculentum* L.). A synthetic acaricide, namely Omite (57% propargite) was also used as a psitive control. For concentration-mortality bioassays, tomato leaf discs were dipped into four different concentrations of the biopesticides, placed on moist cotton wool in petridishes and 15 adult female mites introduced to each disc after one hour. The mortality after 96 hours was low in all biopesticide treatments with the highest value recorded being 53% for Neem + Corn (25ml/l) followed by Neemroc (25ml/l) with 49% mortality. GC- mite (20 ml/l) caused 38% and Achook (2.5 ml/l) 34% mortality. The synthetic acaricide, Omite (2.0ml/l) caused 100% mortality. All the biopesticides and the synthetic acaricide showed strong repellent effect, ranging from 76% to 96% within 6 hours. Mortality resulting from 1 hour residual effect of biopesticides was very low, the highest being only 15 % caused by Achook, compared to 100% caused by the synthetic acaricide, Omite. High mortalities of adults and larvae resulting from contact effect of the biopesticides were observed in all biopesticides except Achook. Achook caused low deaths. Neem + Corn caused 92% mortality, followed by Neemroc (54%), GC- mite (54%) and Achook (33%) mortality of adult female mites at 96 hours. The larvae mortality was higher than that of the adult for the GC- mite (85%) and Neemroc (72%) but lower for Neem + Corn (82%). Achook caused about the same mortality of larvae as of adults (35%). Greenhouse

and field experiments showed Neemroc and Neem + Corn to be more effective in control of *T. evansi* than Achook and GC- mite, although not as much as the Omite. There were no significant differences in yields observed in all the treatments in both greenhouse and the field experiments carried out in this study. The potential of using Neemroc and Neem + Corn formulations in the control of spider mites on tomatoes is evident in this study. Although not as effective as the synthetic acaricide, the biopesticides can be included in the modern pest management programmes where use of synthetic pesticides is not required or is restricted.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Origin and Importance of Tomato (*Lycopersicum esculentum* Mill)

Tomato belongs to the Solanaceae family. It is one of the world's most popular vegetables, with an annual world production of 101 million metric tons in the year 2000 (FAO, 2001). Out of this, 12.6 million metric tons were produced in Africa. In Kenya tomato production was approximately 257,000 metric tons in the year 2000 (MoARD, 2001).

The crop is believed to have originated from Peru-Ecuador and was then domesticated in Mexico. It is reported to have been introduced to East Africa at the beginning of the twentieth century (Groenendijk, 1972) and it possibly arrived via Egypt or Sudan (Tindall, 1983).

Tomato is a fruit vegetable that is consumed fresh (either raw or cooked) and is processed into various products (Di Mascio *et al.*, 1989). Ripe tomato is used in the manufacture of puree, sauces, paste, juice, powder, and ketchup or may be canned as whole fruits. Tomato contains vitamin A and C, potassium and lycopene, a carotenoid that has an antioxidant property. Research has shown that tomatoes confer benefits against prostrate cancer, lung cancer and stomach cancer (Giovannucci, 1999).

1.2 Tomato Production in Kenya

In the past, tomatoes were grown in Kenya for local market only. However, some varieties of tomatoes, such as the cherry type, are now being grown for export though their production is low (HCDA, 2002). Tomato production in Kenya ranks

third after kale and cabbage, but it is the most valuable among these vegetables by contributing USD 51,607,000 in 1999 and USD 56,299,000 in 2000 (Table 1).

Tomato is grown in all provinces with the highest production being from Central, Rift Valley and Nyanza provinces (MoARD, 2001). The major producing districts are Kirinyaga, Murang'a, Nyeri, Meru and Embu. Tomatoes are marketed in the major towns and cities.

1.3 Constraints to tomato production in Kenya

Production problems experienced in growth of tomatoes include pests and diseases, high cost of inputs, poor quality seeds, poor soils and adverse weather conditions (MoARD, 2001). Other problems are uncoordinated and unorganized marketing, exploitation by brokers and poor production planning leading to over-supply in some periods and hence very low prices.

The major diseases of tomatoes include yellow leaf curl disease caused by tomato yellow leaf curl virus, bacterial wilt caused by *Ralstonia solanacearum*, Fusarium wilt, bacterial canker caused by *Clavibacter michiganensis*, early blight caused by *Alternaria solani* and late blight caused by *Phytophthora infestans* (MOARD, 2001). Aphids (*Aphis spp.*), red spider mites (*Tetranychus spp*), African bollworm (*Helicoverpa armigera* Hubner), whiteflies (*Bemisia spp.)* and nematodes (*Meloidogyne spp.*) are among the pests that attack tomatoes. These pests and diseases also constitute a serious problem in production of tomatoes in other parts of Africa (Varela *et al.*, 2003).

Table 1. Vegetable production statistics for Kenya (1999-2000)

	Hacterage (Ha)		Production (MT)		Value (1,000 USD)	
Commodity	**1999**	**2000**	**1999**	**2000**	**1999**	**2000**
Kales	25,966	20,049	351,515	290,610	26,362	31,676
Cabbages	19,150	18,702	255,189	267,336	19,282	14,886
Tomatoes	16,338	15,048	260,037	256,770	51,607	56,299
Chilies	7,738	7,648	55,270	47,092	13,818	11,347
Garden peas	6,039	5,812	29,775	24,593	6,627	5,657
Onions	5,554	5,387	59,688	57,391	15,698	11,046
French beans	5,084	5,276	28,220	22,071	8,658	10,055
Carrots	4,467	4,012	42,438	39,434	4,348	6,354
Asian veg.	2,299	2,101	14,340	10,385	3,930	14,229
Traditional veg.	2,216	2,044	14,561	18,323	4,616	5,088
Spinach	1,735	1,372	16,844	13,585	2,224	1,583
Other minor	477	527	1,848	2,155	426	1,922
Total	**97,067**	**88,878**	**1,129,725**	**1,049,745**	**157,170**	**170,142**

Source: Ministry of Agriculture and Rural Development, Kenya and JICA, 2000

1.4 Red spider mite species on tomatoes in Kenya

Red spider mites are important pests of tomatoes (MOARD, 2001). The most common species of spider mites in Kenya are *Tetranychus evansi* Baker and Pritchard, *T. urticae* Koch, and *T. cinnabarinus* (Boisd.). Until recently *T. urticae*, and *T. cinnabarinus* were the most important spider mites attacking tomatoes in Kenya. However, *T. evansi* identified in the country for the first time in 2001 is more severe than *T. urticae* and *T. cinnabarinus* (Knapp, 2002). Like the other species it causes serious damage to tomatoes by reducing their yield and affecting quality.

1.5 Statement of the problem and justification of the research

Synthetic acaricides are commonly used to control spider mites in Kenya However, their use is facing increasing opposition due to negative impacts, such as environmental pollution and development of resistance by pests. Biological pesticides unlike synthetic pesticides are environment-friendly and are believed to leave no harmful residues on crops. They have also been shown to be safer, selectively toxic and briefly persistence in the environment (Saxena *et al.*, 1984; Stark *et al.*, 1992).

Among the biological pesticides, which may be used are Neemroc, Neem + Corn, Achook and GC-mite. These products are registered in Kenya or are under development but their use in the control of *T. evansi* on tomatoes has not been tried. Studies to evaluate the effectiveness of these biopesticides against spider mites will not only help to solve the problem of mites on tomatoes, but will also ensure human and animal safety and contribute less negative effects to ecosystems. If these biopesticides are found to be effective, they could replace the many synthetic pesticides that are being eliminated from use due to food safety and environmental problems (Koul *et al.*, 1990; Schmutterer, 1990).

1.6 Objectives

1.6.1 Main objective

To evaluate the efficacy of different biological pesticides against red spider mite (*T. evansi*) on tomatoes.

1.6.2 Specific objectives

1) Determination of the effects of Neemroc, Neem + Corn, Achook, GC- mite and Omite on;
    a) Mortality of females of red spider mite (*T. evansi*)
    b) Repellence of red spider mite (*T. evansi*).
    c) Residual effect on red spider mite (*T. evansi*).
    d) Contact effect on red spider mite (*T. evansi*).
2) Determination of the effect of Neemroc, Neem + Corn, Achook, GC- mite and Omite on;
    a) Population of red spider mite (*T. evansi*) in tomatoes.
    b) Leaf damage by red spider mite (*T. evansi*) in tomatoes.
    c) Yield of tomatoes.

1.7 Hypothesis

1) Biological pesticides control red spider mite (*T. evansi*) on tomatoes.
2) The effectiveness of control differs with the type of the pesticide used.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Red Spider Mite (*T. evansi*)

T. evansi, also known as Tobacco spider mite, was first recorded as *T. marianae* McGregor from northeastern Brazil (Silva, 1954) and Mauritius (Moutia, 1958). It was redescribed later as *T. evansi* (Baker and Pritchard, 1960; Moraes *et al.*, 1987) from the material collected in Mauritius. In Africa it was first recorded in Zimbabwe in 1979 (Blair, 1983). The tobacco spider mite is also known to originate from Reunion, Seychelles and Rodriguez (Gutierrez, 1974; Gutierrez and Etienne, 1986), Congo (Bonato, 1999), Morocco (El Jaouani, 1988), Tunisia (Bolland *et al.*, 1998) and USA (Schuster, 1959; Moraes *et al.*, 1987). Recently it was also found in Spain (Ferragut & Ecudero, 1999) and Portugal (Bolland and Vala, 2000). It is believed to have reached Zambia at around 1985 (Mingochi and Jensen, 1986) and Malawi in early 1990s (ICIPE, 1999). In Kenya the species was found in a laboratory culture at ICIPE in March 2001 from mites collected at Mwea irrigation scheme in central Kenya (Knapp, 2002).

2.2 Description and Biology of Red Spider Mites

Adult females of *T. evansi* are oval, orange-red with an indistinct dark blotch on each side of the body. They are about 0.5mm long (Plate 1). Adult males are straw to orange in colour and are smaller than females (Meyer, 1996). Spider mites spin silk threads that anchor themselves and their eggs to the plant. The silk also protects them from their enemies. Adult females may lay over 100 eggs during their life span. Eggs

are whitish and are laid singly, mainly on the underside of the leaf. They hatch after 4 to7 days into larvae that have three pairs of legs and are pinkish in colour. This stage lasts 3 to 5 days, after which it develops into nymph that have four pairs of legs. The total nymphal period lasts 6 to10 days (Plate 1). The nymphs then develop into adults. Reproduction continues throughout the year, resulting in 24 to 30 generations per year (Craemer *et al.*, 1998; Keizer and Zuurbier, 2000). All active stages of mites feed together on the lower sides of leaves and they move to the upper side, stems and fruits when high densities are reached. *T. evansi* is normally active within a temperature range of 16 to 37°C and flourishes at relatively low humidities.

2.3 Damage Caused by Red Spider Mite on Tomatoes

Spider mites prefer the lower surface of leaves. They pierce plant cells and suck out cell contents. Infested leaves first show a white-yellow speckling (Plate 2) that turns bronze as the infestation becomes heavy. As the population increases, the mites may completely cover the plant with webbing (Meyer, 1996; Craemer *et al.*, 1998). Disturbance of metabolic processes of the plant results in decreased growth, flowering and cropping (Mathews and Tunstall, 1994). Crop yields are diminished as essential plant processes are affected.

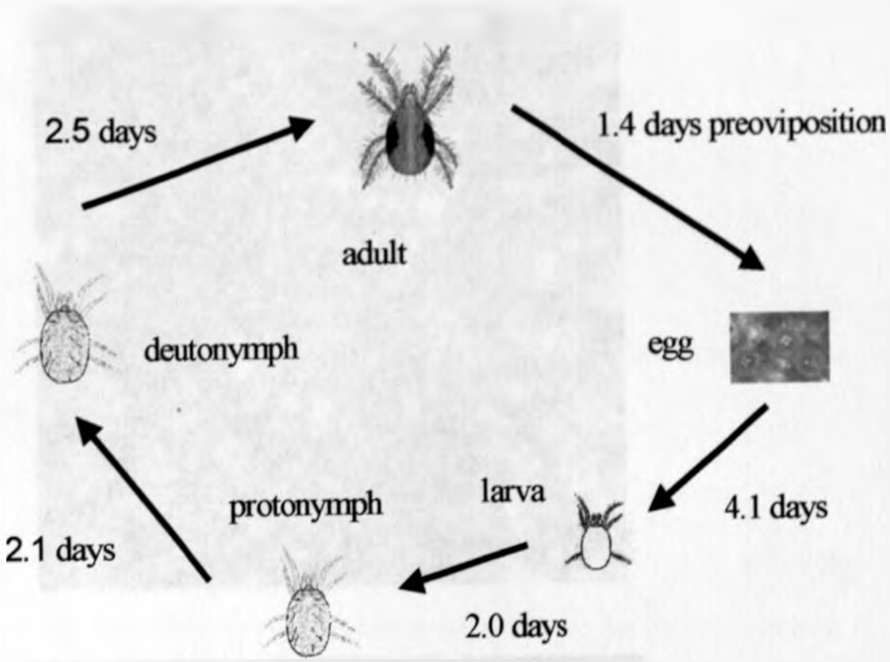

Plate 1 Life cycle of *Tetranychus evansi*. Data from Bonato (1999).

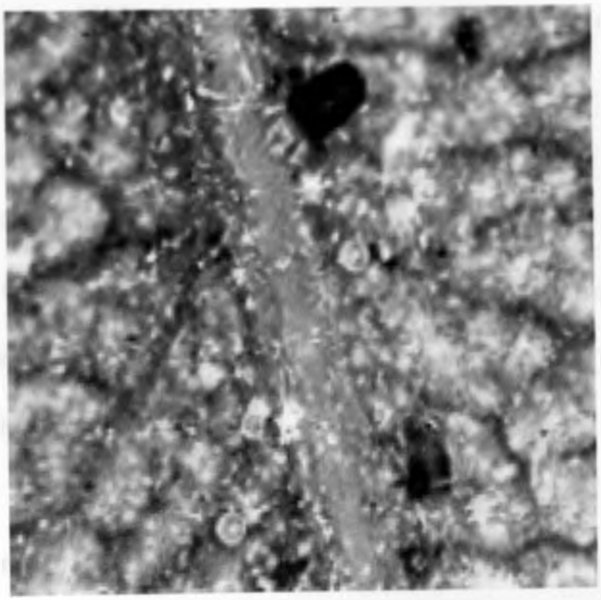

Plate 2 *Tetraychus evansi* and its corresponding symptoms upon infestation of tomato plants (source: Keizer and Zuurbier, 2000)

In tomatoes, yields may be reduced by a mite-induced physiological shock, resulting in reduced size and number of fruits, and sun scalded fruits arising from loss of leaves (McKinlay, 1992). Smaller and lighter fruits with lower contents of soluble solids and ascorbic acid may also be produced (Varela *et al.*, 2003).

2.4 Control Strategies of Spider Mites

Several control strategies are available for the management of red spider mites. These include use of chemical, cultural, biological and botanical methods (Varela *et al.*, 2003).

2.4.1 Chemical control

Different types of acaricides have been widely used for the control of spider mites in tomato. Some synthetic pesticides commonly used include diazinon, dicofol, fenpropathrin, melathion and omethoate (Bohlen, 1978). In Zambia, the control of *T. evansi* with propargite and cyhexatin was found effective (Jensen and Mingochi, 1988).

In Kenya, like in other parts of the world, use of synthetic pesticides is facing a lot of opposition because of toxic residues that the pesticides leave on crops. Continued use of synthetic pesticides results in pests-resistance to pesticides (Blair, 1989; Whalon and Mota-Sanchez, 2000). This has, therefore, resulted in the need to look for alternative control measures that are safe and environmentally friendly. Chemical control of spider mites is sometimes difficult due to webbing. Craemer *et al.*, (1998) reported that difficulty in controlling outbreaks of red spider mites occurs because mites are mostly found on the lower leaf surfaces where webbing protects the mites. Dense foliage and webbing hinders spray penetration and this result in mites

receiving insufficient doses. This problem thus calls for proper spraying of plants to ensure total coverage and enhanced efficient use of the chemical.

2.4.2 Cultural control

The optimal environment for reproduction of spider mites is hot and dry weather. Therefore, high humidities reduce reproductive potential of spider mites. In Finland, Tulisalo (1974) developed a programme of misted water sprays to inhibit development of mite infestations on greenhouse cucumber. The researcher showed that female red spider mites had a shorter life and laid eggs at a slower rate when exposed to high relative humidities, whose water caused death through drowning. Other cultural techniques that may be employed in controlling spider mites include removal and burning of infested plants. This is done especially when infestation is concentrated on a few plants. Separation of infested crops from newly planted crops or nursery areas and burning or removal of infested crop residues and weeds also help to minimize the problem of red spider mites (Keizer and Zuurbier, 2000)

Red spider mites have also been managed by manipulation of plant nutrition, for example, by varying fertilizer regimes. Large quantity of nitrogen, or deficiency of potassium, increases the amount of soluble nitrogen in the plant, resulting in sharp increase in the population of red spider mites (Watson, 1964; Markkula and Tittanen, 1969). Therefore, these conditions should be avoided to keep mite population low

2.4.3 Biological control

The control of spider mites using natural enemies has been widely used mainly in greenhouses. Predacious mites and certain insects have been used as natural

enemies of spider mites (Meyer, 1996). The commonly used predators are from the family Phytoseiidae and occasionally Coccinellidae. The predatory mite *Phytoseiulus persimilis* Athias-Henriot has been successfully used to control *T. urticae* in maize fields (Pickett and Gilstrap, 1986). Moraes & McMutry (1985, 1986) investigated the suitability of *T. evansi* as prey for *P. persimilis* and seven other phytoseiid mites. None of these predators was effective enough to be of practical importance as predator of *T. evansi*. This was because their oviposition and survivorship were very low on this prey.

Since *T. evansi* is an introduced species in Africa, it has no known indigenous predatory mites feeding on it. In Malawi and Zimbabwe a staphylinid beetle, *Oligota spp.* was found preying on *T. evansi*. However, it is difficult to rear this beetle due to its delicate larvae and pupation that occurs in the soil (Knapp pers. comm.).

2.4.4 Botanical pesticides control

In the recent years emphasis on control of crop pests is being focused towards more specific, environment-friendly, natural and biological pesticides, which are not hazardous to both human and animal health (Schmutterer, 1990; Pimentel *et al.*, 1992). Among these pesticides neem (*Azadirachta indica* A. Juss) extracts have received maximum attention of entomologists all over the world (Schmutterer, 1990; Stark and Walter, 1995). This is because the extracts have insecticidal, antifeedant and growth inhibiting properties. Some neem-based pesticides registered and used in Kenya include Neemroc from Saroneem Biopesticides, P. O. Box 64373, Nairobi, Kenya and Achook from Bahar Agrochem and Feeds Pvt. Ltd. E24, M. I. D.C. Industrial Area, Lote Parshuram 415 722 Maharashtra, India. Achook is distributed by Organix Ltd, Nairobi, Kenya. Other formulations on experimental trials include neem

and garlic, neem and pepper, and neem and corn oil also from Saroneem Biopesticides. GC- mite, a garlic extract formulation from Juanco SPS Ltd, P. O. Box 20529, Nairobi, Kenya is a non-neem botanical pesticide that is registered for the control of red spider mites in Kenya.

2.5 Resistance of Spider Mites to Acaricides

The outbreaks of mites and other insect pests of plants have for a long time been controlled by use of conventional broad-spectrum synthetic pesticides that have miticidal properties (Hardman *et al.*, 1993; Hall and Thacker, 1993). Resistance of spider mites to acaricides has been reported in various places (Mansour and Ascher, 1984; Hall and Thacker, 1993). Tetranychidae have been shown to develop resistance to acaricides; for example, *T. urticae* has developed resistance to 72 pesticides. However, the database of arthropods resistance to pesticides does not list *T. evansi* (Whalon and Mota-Sanchez, 2000). Blair (1989) tested 62 acaricide formulations against *T. evansi* on tobacco in the laboratory. He reported that control with dimethoate and thiophosphates was poor. Problems in control of *T. evansi* with dimethoate and other organophosphates have also been reported in Zambia (Jensen & Mingochi, 1988).

2.6 The Neem Tree (*Azadirachta indica)*

2.6.1 Characteristics of the tree

The neem tree belongs to the family Meliaceae. The exact center of origin of the neem tree is unknown (Schmutterer, 1990), but is believed to be somewhere in southeastern and southern Asia, between Indonesia and Iran.

The neem tree grows in tropical climates. It requires an annual rainfall of 400-1200mm and can be grown in different soils as long as there is good drainage. Its temperature requirement ranges from 21-32°C but it can still survive higher temperatures. However it does not withstand freezing. Neem performs best in lowland tropics below 1000m above sea level (Schmutterer, 1990).

Neem was introduced to Africa around 1920. It is established in at least 30 African countries, particularly those in regions along the Sahara's southern fringe (Vietmeyer, 1992). In East Africa, it is found along the coast of Kenya, Somalia and Tanzania (Schmutterer, 1995). In Kenya, neem tree is found in Lamu, Taita Taveta, Kilifi, Mombasa, northeastern Kenya, as well as other semi-arid areas (Loehr *et al.*, 1997).

2.6.2 Biological active ingredients of neem

All parts of the neem tree contain biologically active ingredients (Vietmeyer, 1992). Extracts of neem kernel possess insect antifeedant, sterilant, nematicidal, fungicidal and insecticidal activities (Schmutterer, 1995). More than 100 compounds have been isolated from various parts of the neem tree. The compounds include limonoids, a group of stereochemically homogeneous tetranotriterpenoids, protolimonoids, pentanotriterpenoids and hexanotriterpenoids. Compounds found in neem tree with pesticidal activity are salannin, visalinin, nimbinin, meliantriol and deacetylazadiractinol. Limonoids inhibit growth of a wide range of insect species (Vietmeyer, 1992).

2.6.3 Antifeedant effect

Neem tree extracts reduce or prevent feeding, adversely affect growth, development and reproduction of insects (Schmutterer, 1990). Sundaram and Sloane (1995) reported that neem formulations caused significant reductions in feeding of *T. urticae*. Some chemical components present in neem extracts with insect antifeeding and growth regulatory properties, but which are non-toxic to vertebrates, have been observed (Butterworth and Morgan, 1971; Jacobson *et al.*, 1978). These components are salannin, azadirachtin and meliantriol. Jacobson *et al.* (1978) also showed that a concentration of 0.01-1.0% of a hexane extract of neem seed and its chromatographic fractions significantly deterred feeding by three species of scale insects, citrus red mite and woolly white flies.

2.6.4 Oviposition deterrence

Sundaram and Sloane (1995) have reported reduction in oviposition of mites after placing them on leaf discs treated with pure Azadirachtin (a neem-based biopesticide formulated AZ-A). Experiments using Margosan-o and Neem azal-S (formulations of neem seed kernel extracts) showed that these two products significantly reduced the total number of eggs laid and hatched by *T. urticae* on raspberry leaf disc. (Dimetry *et al.*, 1993). Schauer & Schmutterer (1981) reported a reduction of egg laying per day of *T. urticae* treated with methanolic extracts of neem. A 50% reduction during the first 24 hours was observed.

Although much research has been done on the oviposition deterrence in *T. urticae*, it is worth noting that no work has been done on *T. evansi*.

2.6.5 Mortality effects

Use of neem biopesticides has been reported to kill pests. Mortality of 100% has been reported in *T. urticae* placed on raspberry leaf disc treated with 0.4% Neem azal-S (Dimetry *et al.*, 1993). The use of Azadirachtin (AZ-A) also resulted in mite mortality increased with increase in AZ-Aconcentration (Sundaram & Sloane, 1995).

Knapp and Kashenge (2003) showed that different formulations of neem seed kernel extracts namely Neemroc and Saroneem caused mortality of *T. urticae*. However, mortality was highest where the neem formulations were combined with a synthetic miticide. Information on mortality of *T. evansi* caused by treatment with neem formulations is however not available.

CHAPTER THREE

3.0 DETERMINATION OF THE EFFICACY OF NEEMROC, NEEM + CORN, ACHOOK, GC- MITE AND OMITE IN CONTROL OF *Tetranychus evansi.*

3.1 Introduction

This study was conducted to determine the mortality, repellence, residual and contact effects of three neem-based biopesticides, Achook (0.15% Azadirachtin), Neemroc (0.03% Azadirachtin + 32% neem oil), and Neem + Corn (0.03% Azadirachtin + 32% corn oil), one garlic-based product, namely GC- mite (40% garlic extract) and a synthetic pesticide, namely Omite (57% propargite), on females of *T. evansi*. Adult female mites were used for the laboratory experiments because they are important for multiplication and have been used by other scientists (Dimetry *et al.*, 1993; Sundaram and Sloane, 1995; Knapp and Kashenge, 2003).

3.2 Materials and Methods

3.2.1 Growing of tomatoes

The tomato variety Cal-J obtained from Kenya Seed Company Ltd, P. O. Box 40042, Nairobi, Kenya was used. This tomato variety was chosen because it is susceptible to *T. evansi* infestation and is commonly grown in Kenya for marketing as fresh fruits and as fruits for processing.

The experiments were conducted in laboratories of the International Centre of Insect Physiology and Ecology (ICIPE) at Kasarani, Nairobi, Kenya. International Centre of Insect Physiology and Ecology is located at latitude decimal degrees (dd) – 1.2 South and longitude dd 36.9 East. It is at altitude 1612m above sea level (asl)

receiving annual rainfall of 850 mm and annual mean maximum and mean minimum temperatures of 25.2° C and 13.2° C, respectively (Corbett and O' Brien, 1997).

Experimental tomatoes were grown germination trays and transplanted into pots (14 cm x 15 cm x 8 cm) in a greenhouse at ICIPE premises. The planting media used was three parts of red soil, two parts of cow dung manure and one part of sand. The plants received the recommended management practices including watering, weeding and top-dressing with 150 kg/ha calcium ammonium nitrate (CAN). Upon reaching the required size at one month after transplanting, leaves were harvested to make the leaf discs for laboratory experiments.

3.2.2 Rearing mites and maintenance of mite stock culture

The spider mites used were obtained from infested leaves of tomato plants at ICIPE and the mite stock was reared under controlled conditions in an acclimatized room with a temperature of 25-27°C, 60± 5% relative humidity and a photoperiod of 12/12 hours (Mansour and Ascher, 1984). To maintain the mite stock, tomato variety Money Maker host-plants were sown regularly and once 3 to 4-weeks-old, the fresh plants were placed next to aging plants to enable mites to move to the fresh plants. Individual mites used in bioassays were collected and transferred from infested leaves to leaf discs using a fine hairbrush and with the help of a microscope. Care was taken not to injure the mites, as they are soft-bodied.

3.2.3 Biopesticide formulations

Four biopesticides and a synthetic acaricide were used in laboratory experiments. Of the four-biopesticide formulations, three were neem-based while one was a garlic extract. The neem formulations were (i) Neemroc (a water miscible

formulation with 0.03% Azadirachtin + 32% neem oil), (ii) Neem + Corn (a water miscible formulation with 0.03% Azadirachtin + 32% corn oil) (Saroneem Biopesticides, Box 64373, Nairobi, Kenya), and (iii) Achook (a neem-kernel-based formulation with 0.15% Azadirachtin) (Bahar Agrochem & Feeds Pvt. Ltd. E24, M. I. D.C. Industrial Area, Lote Parshuram 415 722 Maharashtra, India). The non-neem biopesticide used was GC- mite (40% garlic extract + 60% inert ingredients) (Juanco SPS Ltd, Box 20529, Nairobi, Kenya), and the positive synthetic acaricide used was Omite (57% propargite) (Uniroyal Chemical Co. Inc. Middlebury, CT 06749, Connecticut, USA). Achook, Neemroc, GC- mite and Omite are registered for use in Kenya, while Neem + Corn is an experimental formulation under development by the Saroneem Biopesticides Company.

3.2.4 Effects of pesticides on mortality of females of *T. evansi*

Four different concentrations of each biopesticide and the synthetic acaricide were used as follows, Achook: 1.0, 1.5, 2.0, 2.5 ml/l; Neem + Corn: 10, 15, 20, 25 ml/l; Neemroc: 10, 15, 20, 25 ml/l; GC-mite: 5, 10,15, 20 ml/l; Omite: 0.5, 1.0, 1.5, 2.0 ml/l. These concentrations were chosen to oscillate below and above the recommended rates by the manufactures. Water was used as control for each pesticide. Leaf discs (25 mm diameter) were dipped in test solutions for five seconds and placed in 9 cm diameter petridish lined with moist cotton wool. They were left to air-dry for one hour. Batches of 15 adult female mites were then picked from infested leaves, with a fine brush and the help of a microscope and placed on each treated leaf disc. The experiment was laid in a complete randomized design (CRD) and six replications were used for each concentration. The experimental conditions were maintained at 25±2°C temperature and 60±5% relative humidity in an incubator.

Mortality was recorded on each leaf disc after 72 and 96 h post-treatment. Mites were considered dead when they did not respond to gentle prodding with a camel-hairbrush. Percentage mortalities were calculated after excluding mites that strayed away from the leaf discs.

3.2.5 Repellent effect of pesticides on *T. evansi* on tomatoes

A modification of a 'thumbtack' bioassay developed by Weston and Snyder (1990), was used to assess the repellent effects of the pesticides. Leaf discs were cut into halves. One half was dipped in the following pesticides: Achook (2 ml/l), Neem - Corn (25 ml/l), Neemroc (25 ml/l), GC-mite (5 ml/l) and Omite (2 ml/l) for five seconds. The choice of the above concentrations was based on the manufactures recommendations and dosages used by other scientists. Each treated half-leaf disc was placed in a 9 cm diameter petridish lined with moist cotton wool and left to air-dry for one hour. An untreated half leaf disc was used as the control. The treated and untreated halves were carefully attached to form a complete leaf disc as before halving. A thumb pin was fixed at the middle of these leaf discs (Fig. 1). Batches of 15 adult female mites were then picked from infested leaves, with a fine brush and the help of a microscope and placed on the thumb pin. The experiment was laid in a complete randomized design (CRD) and nine replications. The experimental conditions were maintained at 25±2°C temperature and 60±5% relative humidity in an incubator. Mites on each half-leaf disc were recorded 6, 24 and 48 h post-treatment. Mites that moved to the untreated half leaf disc were considered repelled and their mean percentages were calculated as follows:

Repellence (%) = [(%mites in the untreated half disc - %mites in the treated half disc)/ %mites in the untreated half disc] x 100 (Sundaram and Sloane, 1995).

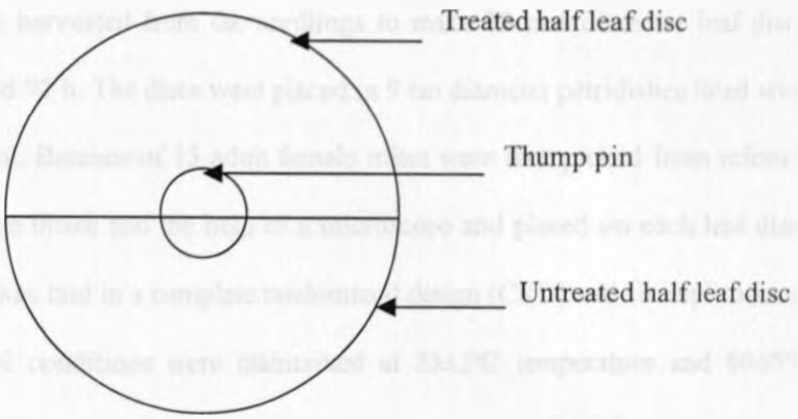

Fig 1. **Sketch of treated and untreated half leaf discs after being joined as used in the repellent experiment**

3.2.6 Residual effect of pesticides on *T. evansi* on tomatoes

One-month-old tomato seedlings in a greenhouse were sprayed with the following pesticides: Achook (2 ml/l), Neem + Corn (25 ml/l), Neemroc (25 ml/l), GC-mite (5 ml/l) and Omite (2 ml/l) using a 1.5 litres hand sprayer. The spray was done to cover both the top and the under side of all leaves and until there was a run-off. Leaves were harvested from the seedlings to make 25 mm diameter leaf discs after 1, 24, 48 and 72 h. The discs were placed in 9 cm diameter petridishes lined with moist cotton wool. Batches of 15 adult female mites were then picked from infested leaves, with a fine brush and the help of a microscope and placed on each leaf disc. The experiment was laid in a complete randomized design (CRD) and six replications. The experimental conditions were maintained at 25±2°C temperature and 60±5% relative humidity in an incubator. Mortality (%) was recorded 48 h post-treatment and percentage mortality was calculated.

3.2.7 Contact effect of pesticides on *T. evansi* on tomatoes

Tomato leaf discs (25 mm diameter) were placed in 9 cm diameter petridishes lined with moist cotton wool. Batches of 15 adult female mites were then picked from infested leaves, with a fine brush and the help of a microscope and placed on each leaf disc. The petri dishes were placed in a plastic tray. The leaf discs were sprayed with Achook (2 ml/l), Neem + Corn (25 ml/l), Neemroc (25 ml/l), GC-mite (5 ml/l) and Omite (2 ml/l) using a 1.5 liters hand sprayer for five seconds and ensuring that the mites were completely covered with the pesticides. The experiment was laid out in a complete randomized design (CRD) and replicated six times. The laboratory conditions were maintained at 25±2°C temperature and 60±5% relative humidity in an incubator. Mortality was recorded in each leaf disc at 24, 48, 72 and 96 h post-

treatment. Percentage mortalities were calculated after excluding mites that strayed from the leaf discs. The same procedure was repeated using larvae. To obtain larvae of a relatively same age, several females were left to lay eggs for four days on tomato leaves placed on petri dishes lined with cotton wool. The females were carefully removed from the leaves leaving the eggs hatch into larvae.

3.3 Statistical Analysis

All data obtained were subjected to analysis of variance using SAS (SAS Institute, 1990). Where significant, the means were separated using Student-Newmans-Keuls test, a post-ANOVA test. Percentage mortality data were Arcsine-transformed using the formula *tx = arsin (sqrt (x/100))* to normalize mean percentages, where *x* = mortality, *tx* = transformed mortality and *sqrt* = square root.

3.4 Results

3.4.1 Effects of pesticides on mortality of females of *T. evansi*

The percentage mortality of *T. evansi* caused by application of different concentrations of biopesticides and a synthetic acaricide are shown in Table 2. Differences in mortality among pesticides were observed. Similarly, significant differences (p=0.05) in mortality among the different concentrations in a pesticide were observed.

Within a pesticide, all concentrations tested resulted in significantly higher mortality than the control. Mortality increased with increase in pesticide concentration and with the duration of growth. However, apart from Neemroc and Neem + Corn, exposure to 72 h and 96 h did not result to significant increase in mortality.

Table 2. Mortality of females of *Tetranychus evansi* exposed to different concentrations of biopesticides after 72 h and 96 h.

Pesticide	Concentration (ml/l)	Mortality (%)[1, 2] ± SE	
		72 h	96 h
Achook	0	1.1 ± 1.1 b	1.1 ± 1.1 d
	1.0	8.8 ± 3.5 ab	10.1 ± 3.6 c
	1.5	11.4 ± 2.7 a	16.6 ± 3.0 bc
	2.0	17.4 ± 4.6 a	23.7 ± 4.4 ab
	2.5	20. 5 ± 5.3 a	34.1 ± 4.7 a
Neem + Corn	0	0.0 ± 0.0 c	0.0 ± 0.0 d
	10.0	17.5 ± 5.5 b	24.5 ± 4.4 c
	15.0	30.1 ± 3.7 a	38.5 ± 2.5 b
	20.0	33.7 ± 5.5 a	50.8 ± 2.7 a
	25.0	33.8 ± 3.6 a	52.9 ± 2.3 a*
Neemroc	0	1.1 ± 1.1 c	1.2 ± 1.1 c
	10.0	12.5 ± 3.1 b	27.4 ± 3.3 b*
	15.0	26.5 ± 4.4 a	46.5 ± 1.9 a*
	20.0	27.3 ± 1.9 a	47.2 ± 4.0 a*
	25.0	28.0 ± 3.8 a	49.3 ± 3.3 a*
GC- mite	0	1.1 ± 1.1 c	1.1 ± 1.1 c
	5.0	7.2 ± 3.7 bc	11.0 ± 3.2 b
	10.0	12.2 ± 3.2 ab	16.9 ± 2.5 b
	15.0	23.6 ± 9.1 a	33.4 ± 6.9 a
	20.0	28.8 ± 5.2 a	38.0 ± 4.1 a
Omite	0	0.0 ± 0.0 c	1.1 ± 1.1 d
	0.5	72.0 ± 5.5 b	76.0 ± 2.7 c
	1.0	82.2 ± 4.6 b	90.7 ± 3.8 b
	1.5	97.6 ± 2.4 a	98.5 ± 1.5 a
	2.0	98.5 ± 1.5 a	100.0 ± 0.0 a

[1] For each formulation, within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

[2] Percentage mortality data were Arcsine transformed before analysis but mean values in the table represent the actual percentage of mortality.

* Indicates that mortality 96 h was significantly higher than at 72 h and without * indicates not significantly higher between the two times of exposure.

All the concentrations of neem-based and non-neem-based biopesticides caused lower mortalities compared to the synthetic acaricide. The highest mortality caused by application of different formulations 72 h after treatment were 21% for Achook at 2.5 ml/l, 34% for Neem + Corn at 25 ml/l, 28% for Neemroc at 25 ml l, 29% for GC- mite at 20 ml/l and 99% for Omite at 2 ml/l on *T. evansi* (Table 2). The highest mortality caused by application of different formulations 96 h after treatment were 34% for Achook at 2.5 ml/l, 53% for Neem + Corn at 25 ml/l, 49% for Neemroc at 25 ml/l, 38% for GC- mite at 20 ml/l and 100% for Omite at 2 ml/l on *T. evansi* (Table 2). In Achook, there were no significant differences in mortality among concentrations 1.5, 2.0, 2.5 ml/l after 72 h. Upon waiting for 96 h, however, increase in mortality was observed among different concentrations of Achook. Similarly in Neem + Corn, there were no significant differences in mortality among concentrations 15, 20 and 25 ml/l. Upon waiting for 96 h, there was increase in mortality caused by concentrations 20 and 25 ml/l that did not differ from each other. No significant differences in mortalities were observed among concentrations 15, 20 and 25 ml/l of Neemroc at both 72 and 96 h. In GC- mite, no significant differences in mortalities were observed among concentrations 15 and 20 ml/l at 72 and 96 h. Concentrations of 5 and 10 ml/l caused similar mortality at 96 h. Concentrations of the synthetic acaricide, Omite (0.5, 1.0, 1.5 and 2.0 ml/l caused the highest mortality compared to biopesticides at 72 and 96 h. There were no differences in mortalities resulting from application of concentrations 1.5 and 2.0 ml/l at both 72 and 96 h.

3.4.2 Repellent effect of pesticides on *T. evansi* on tomatoes

All the pesticides tested showed strong repellent effect on the adult female mites of *T. evansi* throughout the experimental period (Fig. 2; Appendix 14). Mites

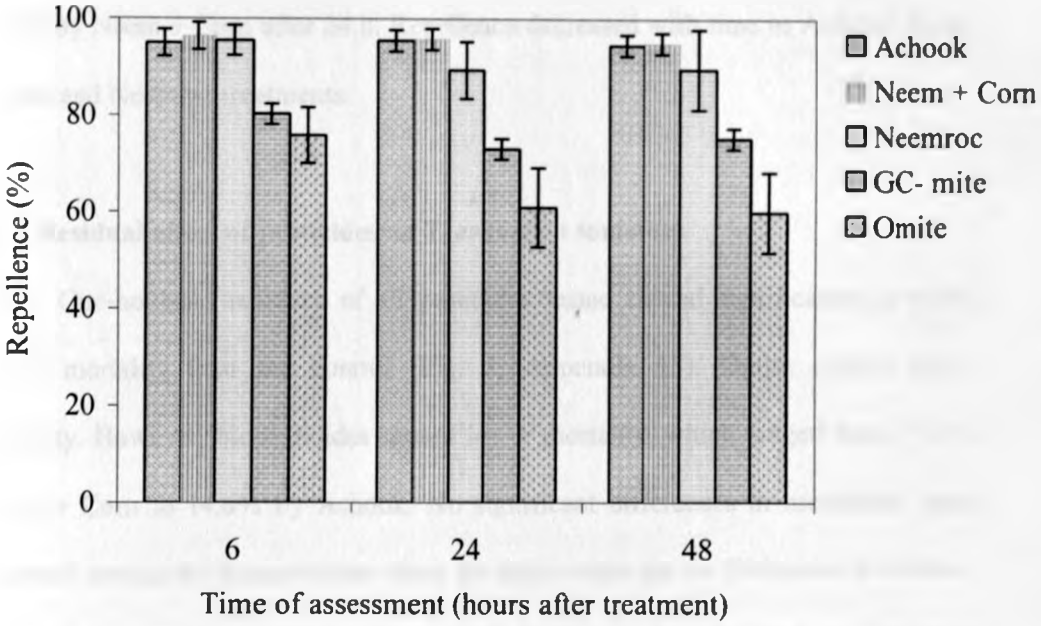

Fig. 2 **Mean repellence ± SE of pesticides on *T. evansi* on tomatoes**

moved from the thumb pin to the untreated half leaf discs. The percentage repellence differed significantly (p=0.05) with the type of biopesticide used. The order from highest to least repellent pesticide was Neem + Corn >Achook = Neemroc > GC- mite = Omite at all times of evaluation. The repellence for the biopesticides ranged from 80.3% by GC- mite to 96.4% by Neem + Corn after 6h and 73.1% by GC- mite to 95.8% by Neem + Corn after 24 h. Repellence decreased with time in Achook, Neem + Corn and Neemroc treatments.

3.4.3 Residual effect of pesticides on *T. evansi* on tomatoes

One-hour-old residues of all pesticides tested caused significantly (p=0.05) higher mortality than the control (Fig. 3; Appendix 15). Omite caused 100% mortality. However, biopesticides caused lower mortality, which ranged from 7% by Neem + Corn to 14.6% by Achook. No significant differences in mortalities were observed among the biopesticides when the mites were put on 24-hour-old residues. Mortality decreased with time in all pesticide treatments. The decrease was observed most on residues of 48 and 72 h.

3.4.4 Contact effect of pesticides on *T. evansi* on tomatoes

When the pesticides were directly sprayed on adult mites, significant differences (p=0.05) in mortalities were observed compared to the control (Fig. 4; Appendix 16). Omite caused the highest mortality while Achook caused the lowest mortality throughout the experimental period. After 24, 48 and 72 h, the synthetic acaricide (Omite) caused significantly higher mortality than all biopesticides. There were no significant differences in mortality among the biopesticides.

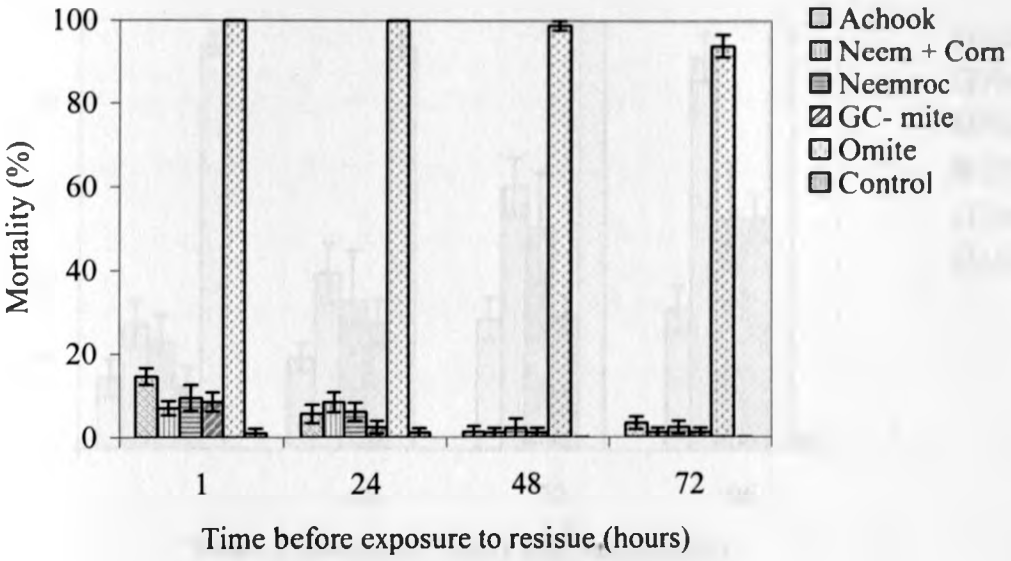

Fig. 3 **Mean mortality ± SE of *T. evansi* exposed to residues of different pesticides. SE is not shown where it was zero.**

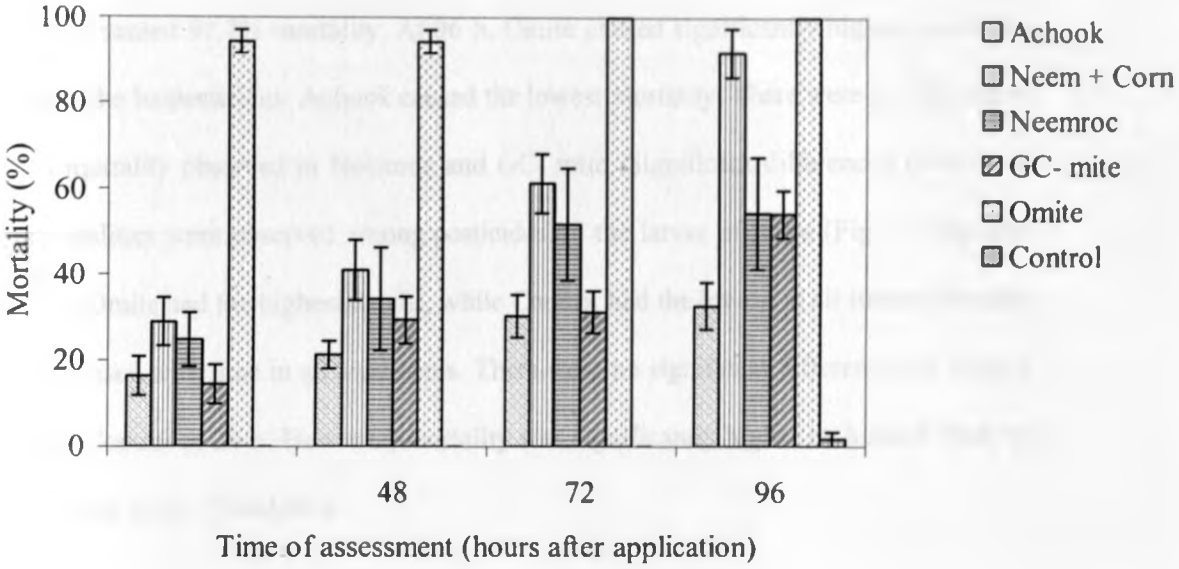

Fig 4 **Mean mortality ± SE of adults of *T. evansi* on tomatoes due to contact effect of pesticides. SE is not shown where it was zero.**

Mortality caused by biopesticides ranged from 14.5% by GC- mite to 29.0% by Neem + Corn at 24 h. Achook and GC- mite caused the least death at 24 h (16.4% and 14.5%, respectively) and at 48 h (21.4% and 29.5%, respectively). Omite caused 94.3% death at 24 h as well as at 48 h. At 72 h, mortality among biopesticides differed significantly (p=0.05). The order from the highest to the lowest mortality was Omite > Neem + Corn> Neemroc> GC- mite= Achook. Omite caused 100%, while Neem + Corn caused 91.7% mortality. At 96 h, Omite caused significantly higher mortalities than the biopesticides. Achook caused the lowest mortality. There were no differences in mortality observed in Neemroc and GC- mite. Significant differences (p=0.05) in mortalities were observed among pesticides on the larvae of mites (Fig. 5; Appendix 17). Omite had the highest deaths, while Control had the lowest at all times. Mortality increased with time in all treatments. There were no significant differences in Achook and Control at 24 h. However, mortality was significantly higher in Achook than the Control at 48, 72 and 96 h.

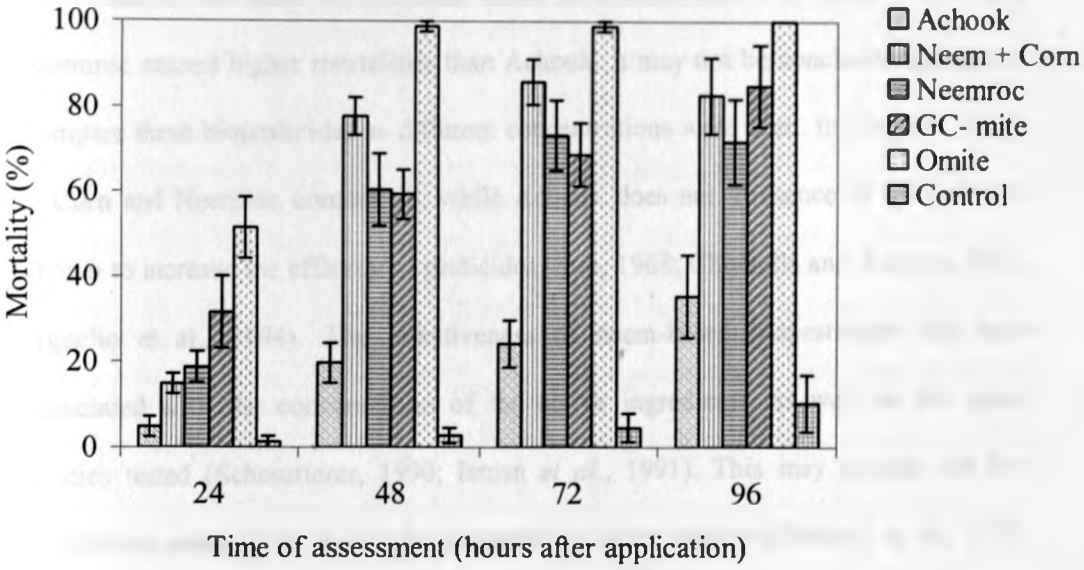

Fig 5. **Mean mortality ± SE of larvae of *T. evansi* on tomatoes due to contact effect of pesticides. SE is not shown where it was zero.**

3.5 Discussion

3.5.1 Effects of pesticides on mortality of females of *T. evansi*

The results from this experiment indicate that neem and garlic-based biopesticides provide some protection against spider mites (*T. evansi*). However, the protection is not as effective as the synthetic acaricide (Omite). The experiment also shows that, of the neem formulations tested the concentrations of Neem + Corn and Neemroc caused higher mortalities than Achook. It may not be conclusive enough to compare these biopesticides as different concentrations were used. In addition, Neem + Corn and Neemroc contain oil, while Achook does not. Presence of oil has been shown to increase the efficacy of pesticides (Sun, 1968; Chinaella and Rovesti, 1992; Agnello et al., 1994). The effectiveness of neem-based biopesticides has been associated with the concentration of the active ingredients, as well as the insect species tested (Schmutterer, 1990; Isman *et al.*, 1991). This may explain the low mortalities obtained in this study compared to other studies (Dimetry *et al.*, 1993; Knapp and Kashenge, 2003). Neem-based biopesticides are reported to kill mites (Dimetry *et al.*, 1993) and this has been confirmed in this current work. Sundaram and Sloane (1995) found Neem-based biopesticides to cause mortality of *T. urticae* and that mortality increased with increase in concentration. In the current study, this was only true for some concentrations, while others performed similarly on the adults of *T. evansi*.

All concentrations of GC- mite caused low deaths of *T. evansi*. This agrees with findings of Boyd Jr. and Alverson (2000), who showed that garlic extracts are not efficient on two spotted spider mites, although it was effective against other arthropods. All concentrations of Omite (a propargite) caused the highest mortalities

in this study. These findings are in agreement with other works that have shown propargite to have effective ovicidal and adulticidal activity on spider mites (Jensen and Mingochi, 1988; Blair, 1989).

It can be concluded that there is need to evaluate the action of the concentrations of biopesticides tested in this study on the other motile stages and the eggs of *T. evansi*, since mortalities of adults were low. For Omite, even the lower concentration used in this study can effectively control mite.

3.5.2 Repellent effect of pesticides on *T. evansi* on tomatoes

All the pesticides tested in this study showed strong repellence of the adults of *T. evansi*. Neem-based pesticides have been reported to have a very strong repellence effect on spider mites (Dimetry *et al.*, 1993). This report agrees with findings of the current study, where all the neem-based biopesticides exhibited very strong repellence of *T. evansi* that moved from treated half leaf discs to the untreated half leaf discs. The findings of this study also agree with findings of Mansour and Ascher (1983), who found that extracts of neem seed kernels prepared in various solvents strongly repelled the adult females of *T. cinnabarinus* from treated leaves and reduced egg-laying. Sundaram and Sloane (1995) tested repellence of some neem-based formulations and pure azadirachtin and found them to repel *T. urticae*. The researchers reported percentage repellence of 97%. In the current study, the highest repellence recorded was 96.4%. All the biopesticides, tested caused over 73% repellence of *T. evansi*. Schauer and Schmutterer (1981) and Knapp and Kashenge (2003) also showed methanol and aqueous extracts of neem seed kernels to have strong repellent effect on *T. urticae*. GC- mite, a garlic extract, was found to repel adults of *T. evansi* in this study. Repellent effect of garlic extracts on *T. urticae* has

been evaluated in the laboratory and greenhouse settings (Boyd Jr. and Alverson, 2000). The laboratory experiment showed some repellence of mites, while the greenhouse experiment did not. These findings agree with the results from the present work. Omite, a propargite also repelled *T. evansi* in this study, although there is no literature to support this observation. Although beneficial, repellence of mites by pesticides may have a negative effect in mite control. This is because mites take refuge in areas of the plant that are not fully covered with the pesticide. Pest resurgence in the field starts from these refuges after the activity of the pesticide diminishes (Gould, 1991).

3.5.3 Residual effect pesticides on *T. evansi* on tomatoes

Low mortality of *T. evansi* resulting from residual effects of biopesticides was observed in the current work. The mortality was far less compared to that of the synthetic acaricide. Schmutterer (1988) stated that under tropical conditions, the residual action of neem averages about 5 days. In the current study, mortality was very low even after 1 hour. Neem biopesticides are reported to have short persistence (Saxena *et al.*, 1984; Stark *et al.*, 1992). This may explain the low mortality caused by the biopesticides in the current study. Low mortalities obtained in the current study could also be because botanical pesticides disintegrate fast when sprayed on plants and thus have relatively short persistence in the environment compared to synthetic acaricides. Short persistence is a disadvantage for pest control because in case of a re-infestation of mites on plants previously sprayed with biopesticides, population of mites will generally increase resulting to crop loss. Re-surgence may require frequent spraying, which may not be economical to the farmer. GC- mite, a garlic extract, resulted to low mortalities in this study. This result agrees with findings of Boyd Jr

and Alverson (2000), who found garlic to be ineffective on spider mites (*T. urticae*) of roses. Low residual action is advantageous, because crops have lower residues at the time of consumption, thus posing less risk to human health. This is one of the desirable characteristics of botanical biopesticides, which are popular in this era that people are much concerned about their health.

3.5.4 Contact effect of pesticides on *T. evansi* on tomatoes

All pesticides tested in this study caused mortality when directly sprayed on adults and larvae of *T. evansi*. Among the neem formulations tested, Achook caused the least mortality on both adults and larvae, although it had the highest percentage of azadirachtin (0.15%). This response could probably be explained by the fact that Azadirachtin does not contribute to the acaricidal activity of the neem-based biopesticides (Mansour and Ascher, 1984; Schmutterer, 1995). Neemroc and Neem + Corn are oil formulations, which caused high mortalities. Their good performance could be attributed to the presence of the oil. This explanation is supported by findings of Jacobson *et al.* (1978), Schauer and Schmutterer (1981), and Dimetry and Schmidt (1992), who observed that neem oil formulation elicited a very good feeding deterrent activity to citrus red mite (*Pananychus citri*), two spotted spider mite (*T. urticae*) and the bean aphid (*Aphis fabae* Scop). The effectiveness of neem oils in the control of mites was also demonstrated by Sanguanpong and Schmutterer, 1992. Oils are known to increase the insecticidal activity of pesticides. Sun (1968) showed oil-based insecticides to be more toxic to housefly (*Musca domestica* L.) than non-oil-based insecticides. The increased efficacy caused by oils is believed to be mediated by increased penetration and persistence of pesticides into crops and insects when directly applied. Treacy *et al.* (1986, 1991) and Stark and Walter (1995) working on

pea aphid found neem oil and other oils to increase the efficiency of insecticides. Polar components of neem oil may also contribute to increased biological activity of neem insecticides. Blocking of the stigma by the oil film spreading on the body of mites or any other pests probably increased death (Chinaella and Rovesti, 1992). This effect may explain why direct spraying biopesticides with oil components on spider mites caused higher mortality than when mites were introduced to leaf discs that had previously been sprayed with the same pesticides. Findings of Agnello *et al.*, (1994) also agree with the current study. The researchers showed that mineral oils are effective in the control of mites.

GC- mite, a garlic extract caused substantial mortalities of adults and larvae of spider mites in this study. These findings, however, disagree with Boyd Jr. and Alverson (2000), who found garlic not to be effective on spider mites (*T. urticae*) of roses. All biopesticides caused higher mortalities of larvae than of adults of *T. evansi*. This result may be because biopesticides, especially neem-based, disrupt molting, development and reproduction of insects (Schmutterer and Ascher, 1984; Koul *et al.*, 1990).

The synthetic acaricide (Omite) caused the highest mortalities of adults and larvae regardless of the method it was applied to the leaf discs. This result agrees with findings of Blair (1989), who tested 62 acaricide formulations against *T. evansi* on tobacco in the laboratory and observed poor control with dimethoate and thiophosphates. Jensen and Mingochi (1988) reported problems in control of *T. evansi* using dimethoate and organophosphates, but they found cyhexatin and propargite to effectively control the mites. Omite, being a synthetic acaricide and having long persistence as shown in this study, may pose health risks. It may also be undesirable for many consumers, who have recently become very conscious of their health.

CHAPTER FOUR

4.0 EFFICACY OF ACHOOK, + CORN, NEEMROC, GC- MITE AND OMITE ON *Tetranychus evansi* ON TOMATOES UNDER GREENHOUSE AND FIELD CONDITIONS

4.1 Introduction

While a lot of research has been carried out on the use of botanical pesticides against different pest species, no study has been reported on the efficacy of Achook, Neemroc, Neem + Corn, GC- mite and Omite in the control of red spider (*T. evansi*) under greenhouse and field conditions. The objective of this study was, therefore, to determine whether Achook, Neemroc, Neem + Corn, GC- mite and Omite are effective in the control of *T. evansi.*

4.2 Materials and Methods

4.2.1 Efficacy of pesticides on *T. evansi* on tomatoes under greenhouse conditions

Tomato variety Cal-J obtained from Kenya Seed Company Ltd, P. O. Box 40042, Nairobi, Kenya was used in the experiment. This tomato variety was chosen because it is susceptible to *T. evansi* infestation and is commonly grown in Kenya for the fresh market and processing industries.

The experiment was conducted between April and August 2003 in greenhouses at JKUAT and International Centre of Insect Physiology and Ecology (ICIPE) at Kasarani, Nairobi, Kenya. Geographical location of ICIPE at latitude decimal degrees (dd) –1.2 South and longitude dd 36.9 East. It is at altitude 1612m above sea level (asl) and receives an annual mean rainfall of 850 mm and the annual

mean maximum and minimum temperatures of 25.2° C and 13.2°, C respectively (Corbett and O' Brien, 1997).

Tomato seeds were sown in germination trays. Three weeks after germination, 72 seedlings were transplanted into plastic pots (25 cm x 32 cm x 20 cm) filled with a mixture of topsoil, sand and manure at a ratio of 2:1:1 and double ammonium phosphate (DAP) at a rate of 200 kg/ha. The potted plants were then transferred to a greenhouse at Jomo Kenyatta University of Agriculture and Technology (JKUAT), which is located at latitude 01° 01'S, longitude 37° 06'E and altitude 1600 m asl and receives annual rainfall of about 950 mm (Jaetzold and Schmidt, 1983). Jomo Kenyatta University of Agriculture and Technology is found in Thika district, Central province in Kenya. The six pesticides used were 25 ml/l Neemroc, 25 ml/l Neem + Corn, 2 ml/l Achook, 5 ml/l G C- mite, 2 ml/l Omite and water (control). The sources are as previously stated.

The treatments were laid out in a complete randomized design and replicated three times. Each plot consisted of four potted plants. The plants were watered regularly, ensuring that they had enough moisture. Top dressing with 150 kg/ha calcium ammonium nitrate (CAN) was done one month after transplanting. Pruning was done leaving one or two main stems to grow. Laterals were pinched off weekly. Staking was done using a 2-metre tall post. The post was put firmly in the pot for each tomato plant. Tomato stems were loosely tied on the post using a sisal twine as each plant grew (MoARD, 2000). The temperature in the greenhouse ranged from 15-34.9°C and the mean relative humidity was 52%.

Three weeks after transplanting of tomato seedlings, each plant was artificially infested with 100 adult *T. evansi* mites of both sexes. Infestation was achieved by directly picking the mites using a fine hairbrush from a colony maintained on tomato

plants grown in the laboratory at ICIPE. The mites were evenly distributed on all the leaves and allowed 21 days to establish and multiply before administration of treatments. The treatments were administered 3 and 5 weeks after infestation by spraying tomatoes plants outside the greenhouse using a 1.5-litre hand sprayer to avoid spillage between the treatments.

The variables that were measured were leaf damage index (LDI), number of mites per leaf area and yield of tomatoes. Leaf damage index was established visually using modification of a method described by Hussey and Scopes (1985). The visual rating scale used for leaf damage ranged 0 to 5, where 0 = no damage, 1= 1-15%, 2= 20-30%, 3= 35-50%, 4= 55-70% and 5= 80-100%. The initial leaf damage assessment was done just before the first treatment (3 weeks after infestation) and thereafter every two weeks. The score was done on two plants per plot. On each plant three leaflets obtained from the top, middle and lower sections were assessed to determine the damage.

Number of mites per leaf area was determined every two weeks. First count was done just before the first treatment (3 weeks after infestation). To determine the number of mites, two plants were sampled per plot and from each plant, three terminal leaflets were obtained from one leaf at the top, middle and lower sections. The leaflet were kept separately in labeled paper bags and carried in a cool box maintained at 4°C to a laboratory at ICIPE, where counting was done using a microscope and a tally counter. After counting mites, the leaves were placed back in the paper bags and taken to a laboratory at JKUAT for measurement of leaf area using a leaf area meter. Calculations were made to establish the average number of mites per cm^2 leaf area.

Tomato fruits were harvested upon ripening. For each treatment, fruits were graded into large, small and rejects. Large fruits averaged 60 g and above, while small

tomatoes included any other marketable sizes. Weight was measured using a balance calibrated in grams to establish yield.

4.2.2 Efficacy of pesticides on *Tetranychus evansi* on tomatoes under field conditions

Tomato seeds of variety Cal-J obtained from Kenya Seed Company Ltd, P. O Box 40042, Nairobi, Kenya were used for the two field experiments. This tomato variety was chosen because it is susceptible to *T. evansi* infestation and is commonly grown in Kenya for fresh market and processing industries. Tomato seedlings for the two field experiments were sown in germination trays in a greenhouse at the International Centre of Insect Physiology and Ecology (ICIPE) on 11th November 2002 and 24th June 2003, for the first and second experiments, respectively.

One month after sowing on 10th December 2002 and 22nd July 2003 tomato seedlings were transplanted to the field at the University of Nairobi, Upper Kabete Campus, Kenya. Kabete is located at latitude 1° 15' South, longitude 36° 44' East and altitude 1829 m asl. It experiences mean maximum and minimum temperature of 23° C and 13° C, respectively. The coolest months are June, July and August, while the hottest months are December, January and February. The area has a bimodal rainfall regime and the annual average of 1046 mm. Soils at Kabete have been described as humic nitosols well-drained, extremely deep, dusk to red to dark-reddish brown friable clays (Jaetzold and Schmidt, 1983). The mean maximum temperatures during the experimental periods were 25.1°C and 22.4°C for the first and second experiments, respectively, while the mean rainfall was 110.4 mm and 51.4 mm for the first and second experiments respectively (Metrological Dept. Kabete, 2003).

The treatments were the same as greenhouse. However, GC- mite treatment was excluded in the first trial, as it was not available.

The treatments were laid out in a complete randomized block design (CRBD). Four blocks (replications) were used and separated by a 2 m path. Five and six plots of 3 m x 5 m were used per block and a 1.5 m path separated them for the first and the second trials, respectively. Rows spaced 60 cm apart were used per plots while plants were spaced at 45 cm within rows.

Double ammonium phosphate (DAP) was used during transplanting at a rate of 200 kg/ha. Top dressing with calcium ammonium nitrate (CAN) was done one month after transplanting at rate of 150 kg/ha. Watering was done regularly and the field was maintained weed-free. Pruning was done, leaving one to two main stems to grow. Laterals were pinched off weekly or as they grew. Staking was done using a 2-meter tall post. The post was put firmly in the ground near each tomato plant. Stems were loosely tied using a sisal twine onto the post as the plant grew (MoARD, 2000). Tomatoes were sprayed with 2 g/l Milraz, a fungicide to control blight. In the first field experiment, tomato plants were infested naturally with spider mites from fields near the experimental plot. In the second experiment, tomato plants were infested artificially with red spider mites, because natural build up of the mites was slow due to the cold weather of July and August. Infestation was done on 20th August and 16th September 2003 by placing infested tomato leaves obtained from a farmer's field at Mwea area, Central province, Kenya, among experimental tomatoes.

In the first experiment, treatments were applied during the 9th and 11th week after transplanting. In the second, treatments were applied during the 12th and 14th week after transplanting because of delay in infestation. Infested plants were sprayed using a 15-litres commercial knapsack sprayer until run-off to ensure complete

coverage. The knapsack sprayer was thoroughly washed with soap and water after each applying treatment to ensure contamination did not occur.

The variables that were measured in the field experiments were leaf damage index (LDI), number of mites per three leaflets, and yield. Leaf damage index was established using a slightly modified method of Hussey and Scopes (1985). The visual rating scale ranged from 0 to 5 where 0 = no damage, 1= 1-15%, 2= 20-30%, 3= 35-50%, 4= 55-70% and 5= 80-100%. The initial leaf damage assessment was obtained just before the first treatment and thereafter weekly. The score was done on three plants per plot. On each plant, three leaflets were sampled from the top, middle and lower sections and assessed to determine the damage.

Number of mites per three leaflets was determined weekly. First count was done just before the first treatment and thereafter weekly. To determine the number of mites, three randomly selected plants were sampled per plot and marked with a thread of a different colour each week of sampling to ensure they were not repeated. From each plant, three terminal leaflets were obtained from the top, middle and lower sections. The leaflets from the different sections were kept separately in labeled paper bags and carried to the laboratory in a cool-box maintained at 4°C. Counting of mites was done at the ICIPE laboratory using a microscope and a tally counter. All motile stages of the mites were counted.

Tomato fruits were harvested upon ripening. They were graded into large and small fruits. Weights were measured using a 25-kg spring balance and recorded. Large fruits averaged 65 g and above, while small tomatoes included any other marketable tomatoes. Unmarketable fruits were also recorded and included those damaged by spider mites.

4.3 Statistical Analysis

Mite counts data from the greenhouse and field trials were logarithmically transformed using the formula $tx = log_{10}(x+1)$, where tx = transformed number of mites and x = original number of mites, to ensure normal distribution and independence of the variance from the mean (Little and Hills, 1978). The data were subjected to analysis of variance using SAS (SAS Institute, 1990). Where significant the means were separated using Student-Newmans-Keuls test, a post ANOVA test..

4.4 Results

4.4.1 Efficacy of pesticides on *T. evansi* on tomatoes under greenhouse conditions

a) Spider mite populations

Prior to treatment, the mites were equally distributed in all the treatments and ranged from 0.5 to 2.0 mites/cm^2 leaf area (Fig. 6; Appendix 18). A similar distribution was also observed during the third week after treatment. Although there was reduction in the number of spider mites (ranging from 0.1 to 1.0). there was no significant difference in the number of spider mites/cm^2 of the leaf in all the treatments during the third week.

During the fifth week, the mite population differed significantly (p=0.05) among the treatments. Control had the highest population of 7.2 mites/cm^2 followed by GC-mite and Achook that were not different from each other with 4 and 3 mites/cm^2 respectively. Neemroc and Neem + Corn were equally effective with 0.7 and 0.4 mites/cm^2, respectively. There were no mites on tomatoes treated with Omite.

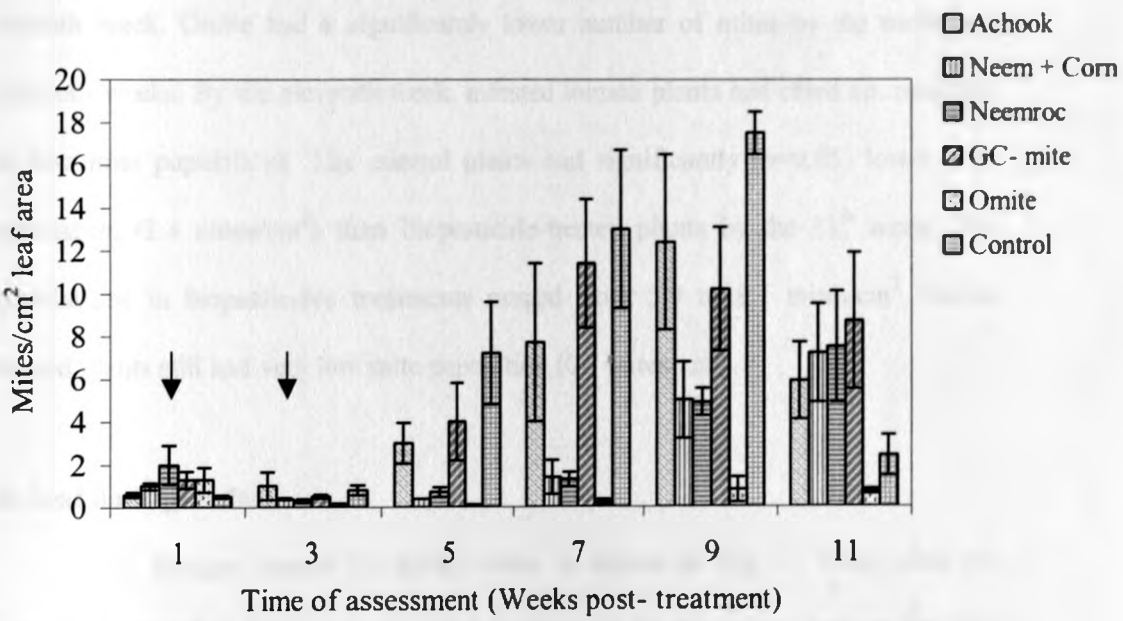

Fig. 6. Mean number ± SE of red spider mites in greenhouse grown tomatoes treated with different pesticides. Arrows show times when treatments were applied.

Significant differences (p=0.05) were also observed among the treatments during the seventh and ninth weeks. Control had 13.0 and 17.5 mites per cm^2 at seventh and ninth week, respectively. Achook and GC- mite did not significantly (p=0.05) differ from the control, during the seventh week and had 7.7 and 11.4 mites/ cm^2, respectively. Neemroc, Neem + Corn and Omite were equally effective during the seventh week. Omite had a significantly lower number of mites by the ninth and eleventh weeks. By the eleventh week, infested tomato plants had dried up, resulting in low mite populations. The control plants had significantly (p=0.05) lower mite population (2.4 mites/cm^2) than biopesticide-treated plants by the 11^{th} week. The populations in biopesticides treatments ranged from 5.9 to 8.7 mites/cm^2. Omite treated plants still had very low mite population (0.7 mites/cm^2).

b) Leaf damage index

Leaf damage caused by spider mites is shown in Fig. 7. There were no significant (p=0.05) differences in leaf damage in all the treatments prior to the first and second applications (first week to fifth week). In the first week, LDI ranged from 0.8 to 1.1. In the third week, it ranged from 1.9 to 2.5, while in the fifth week it ranged from 1.0 to 3.5. During the seventh week, all treatments had different damage indices, but scores were significantly lower than the control. The order of damage from highest to lowest was control> GC-mite> Achook> Neem + Corn= Neemroc> Omite. During the ninth and eleventh weeks, spider mites caused similar damages in all biopesticide treatments and the control. However, tomatoes treated with Omite still suffered significantly lower damage than all the treatments after ninth and eleventh weeks. Plates 3, 4, 5, 6, 7 and 8 show mite damage at seven weeks post-treatment.

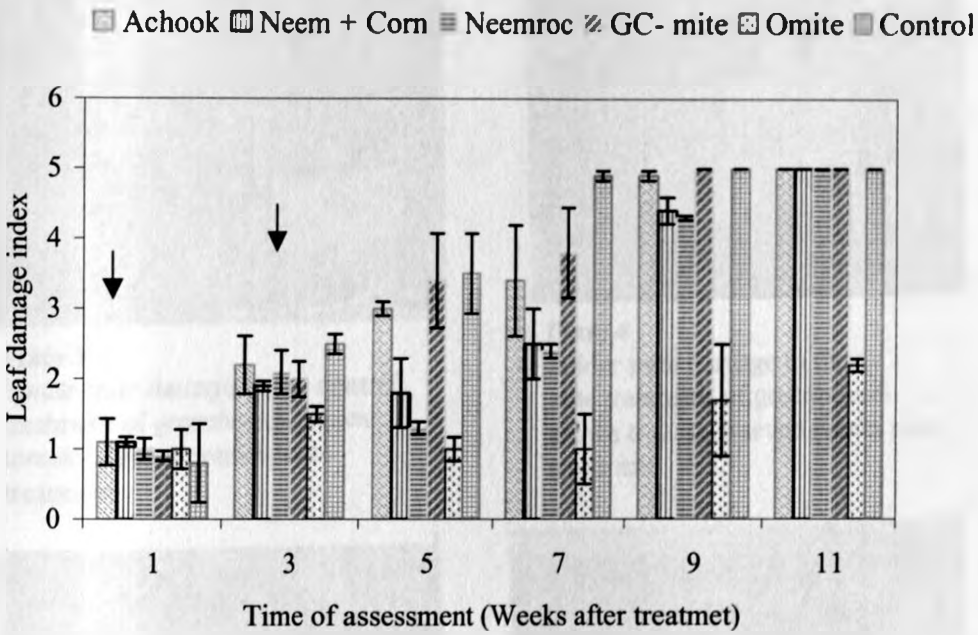

Fig. 7. Mean leaf damage ± SE by red spider mites on greenhouse grown tomatoes treated with different pesticides. Arrows show time when treatments were applied.

Plate 3
Spider mite damage in the control treatment of greenhouse-grown tomatoes seven weeks post-treatment

Plate 4
Spider mite damage in the GC-mite treatment of greenhouse-grown tomatoes seven weeks post-treatment

Plate 5
Spider mite damage in the Achook treatment of greenhouse-grown tomatoes seven weeks post-treatment

Plate 6
Spider mite damage in the Neemroc treatment of greenhouse-grown tomatoes seven weeks post-treatment

Plate 7
Spider mite damage in the Omite treatment of greenhouse-grown tomatoes seven weeks post-treatment

Plate 8
Spider mite damage in the Neem & Corn treatment of greenhouse-grown tomatoes seven weeks post-treatment

C). Yields

There were no significant differences (p=0.05) in the yield for all the treatments (Table 3).

Table 3. Effects of application of different pesticides on the yield of greenhouse-grown tomatoes

Treatment	Mean yield of tomatoes in the greenhouse		
	Large (L) (kg/plant)	Small (S) (kg/plant)	L + S (kg/plant)
Achook	0.33	0.15	0.48
Neem + Corn	0.30	0.13	0.43
Neemroc	0.34	0.16	0.50
GC-mite	0.23	0.17	0.40
Omite	0.33	0.16	0.49
Control	0.28	0.18	0.46

[1] Means were not significantly different

4.4.2 Efficacy of pesticides on *Tetranychus evansi* on tomatoes under field conditions

a) Spider mite populations

There were significant differences in the number of mites during the first week, prior to the application of the treatments in the first experiment. Achook and Neem + Corn had significantly (p=0.05) higher number of mites than the other treatments that had similar distribution of mites (Fig. 8; Appendix 20). The number of mites ranged from 12 to 44 per 3 leaflets. In the second and third weeks, the number of spider mites in the control and biopesticide-treated plants were not significantly different. Mite population continued to increase and was maximum at the sixth week. However, the population decreased thereafter. During the sixth week, significant (p=0.05) differences among pesticide treatments were observed. Achook was not different from the Control and recorded significantly (P=0.05) higher mite population than Neemroc and Neem + Corn. At seven weeks, due to high infestations by mites, tomato plants had dried up, especially in the control and Achook treatments, and the populations were the same for all the biopesticides. Omite treated plots had consistently the lowest number of mites, throughout the experimental period.

In the second field experiment, mites per three leaflets were equally distributed in all the treatments prior to application of treatments (first week) and ranged between 22 to 37 mites per 3 leaflets (Fig. 9; Appendix 21). Similarly, during the second and the third weeks, there were no significant differences in the number of mites/ three leaflets among the treatments apart from Omite. Omite had the lowest number of mites per 3 leaflets. Clear differences among biopesticide treatments were observed during the

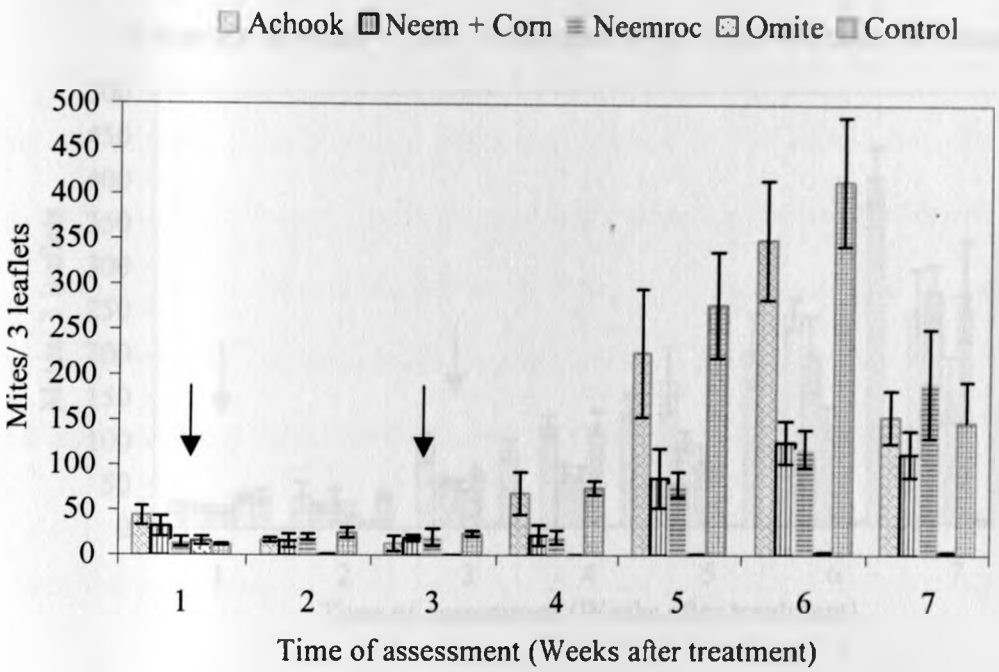

Fig. 8. **Mean number ± SE of red spider mites on field-grown tomatoes treated with different pesticides in the first experiment. Arrows when treatments were applied.**

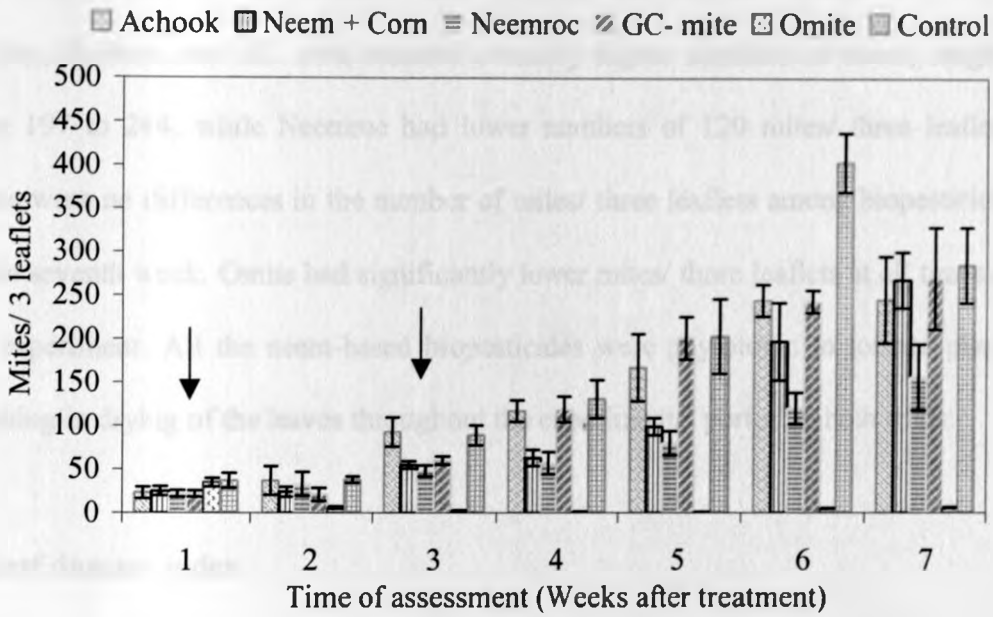

Fig. 9. **Mean number ± SE of red spider mites on field-grown tomatoes treated with different pesticides in the second experiment. Arrows show when treatments were applied.**

fourth and fifth weeks. Neemroc and Neem + Corn-treated plots revealed significantly lower numbers of mites than plots of Achook, GC- mite and Control, which were not different from each other. Significantly, higher mite numbers were observed during the sixth week in the Control than in the rest of the treatments. Neem + Corn, Achook and GC- mite resulted similarly higher numbers of mites, ranging from 197 to 244, while Neemroc had lower numbers of 120 mites/ three leaflets. There were no differences in the number of mites/ three leaflets among biopesticides in the seventh week. Omite had significantly lower mites/ three leaflets at all times of the experiment. All the neem-based biopesticides were phytotoxic to tomato plants resulting in drying of the leaves throughout the experimental period in both trials.

b) Leaf damage index

The results for leaf damage caused by spider mites in the first field experiment are shown in Fig. 10 and Appendix 22. There were no significant differences ($p=0.05$) in leaf damage in the treatments prior to the first application of the pesticides (first week). Leaf damage increased in the Control and biopesticide-treated plants after the third week. However, leaf damage was lower and decreased in the Omite-treated plants. During the fourth and fifth weeks, leaf damage in biopesticides Neem + Corn and Neemroc were significantly ($P=0.05$) lower than in both Achook and control treatments. There were no significant differences in leaf damage among the biopesticide-treated plants during the sixth and seventh weeks.

In the second field experiment, all treatments exhibited similar leaf damage by the spider mites from first to third week (Fig. 11; Appendix 23). From the fourth week

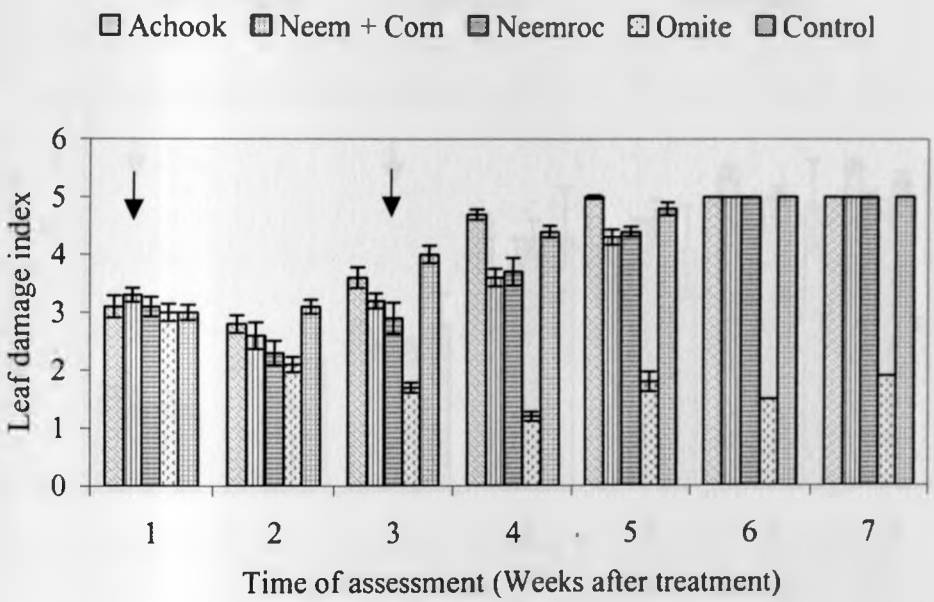

Fig. 10. **Mean leaf damage ± SE of red spider mites on field-grown tomatoes treated with different pesticides in the first experiment. Arrows show when treatments were applied.**

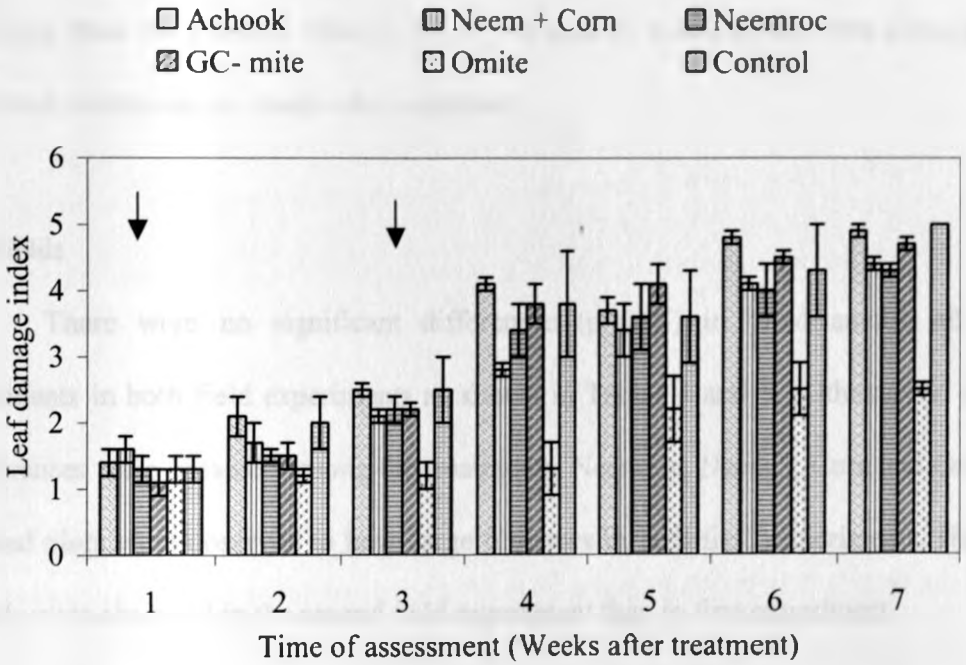

Fig. 11. **Mean leaf damage ± SE by red spider mites on field-grown tomatoes treated with different pesticides in the second experiment. Arrows show when treatments were applied.**

to the sixth week, leaf damage was significantly (p=0.05) lower in the Omite-treated plants than in all other treatments that had similar damage. In the seventh week, there were significant differences in damage among the treatments. Achook was not different from the Control. Plate 9, 10, 11, 12 and 13 shows spider mite damage on different treatments six weeks after treatment.

c) Yields

There were no significant differences (p=0.05) in yield among all the treatments in both field experiments as shown in Tables 4 and 5. Although no yield differences were obtained among the treatments, Neemroc, Neem + Corn and Omite-treated plots were observed to have large tomatoes in both field experiments. Higher yields were observed in the second field experiment than in first experiment.

Plate 9
Spider mite damage in the Control treatment of field-grown tomatoes six weeks post-treatment

Plate 10
Spider mite damage in the Achook treatment of field-grown tomatoes six weeks post-treatment

Plate 11
Spider mite damage in the Neemroc treatment of field-grown tomatoes six weeks post-treatment

Plate 12
Spider mite damages in the Neem + Corn treatment of field-grown tomatoes six weeks post-treatment

Plate 13
Spider mite damage in the Omite treatment of field-grown tomatoes six weeks post-treatment

Table 4. Effects of application of different pesticides on the yield of field-grown tomatoes in the first field experiment

Treatment	Mean yield of tomatoes in the field[1]			
	Large (Kg/plant)	Small (Kg/plant)	L + S (Kg/plant)	Rejects (Kg/plant)
Achook	0.21	0.22	0.43	0.14
Neem & Corn	0.15	0.21	0.36	0.09
Neemroc	0.22	0.23	0.45	0.08
Omite	0.21	0.21	0.43	0.09
Control	0.21	0.22	0.42	0.09

[1] Means were not significantly different

Table 5. Effects of application on different pesticides on the yield of field-grown tomatoes in the second field experiment

Treatment	Mean yield of tomatoes in the greenhouse[1]			
	Large (L) (Kg/plant)	Small (S) (Kg/plant)	L + S (Kg/plant)	Rejects (Kg/plant)
Neem & Corn	0.14	0.50	0.64	0.11
Neemroc	0.23	0.55	0.78	0.12
GC-mite	0.19	0.53	0.72	0.15
Omite	0.24	0.57	0.81	0.13
Control	0.17	0.46	0.63	0.15

[1] Means were not significantly different

4.5 Discussion

4.5.1 Efficacy of pesticides on *T. evansi* on tomatoes under greenhouse and field conditions

a) Spider mites populations

In both greenhouse and field experiments, Neemroc and Neem + Corn treatments consistently showed lower populations of spider mites compared to Achook and GC- mite. Nevertheless, Omite had the lowest populations than the rest of the treatments. Laboratory experiments carried out in this study to determine the contact effect of these biopesticides on adult mites agree with these findings where Achook and GC-mite killed less mites in 72 h compared to Neemroc and Neem + Corn. The effectiveness of Neemroc and other neem formulations in tomatoes grown in the greenhouse was also confirmed by findings of Kashenge (1999). Neem oil and Corn oil-based biopesticides were found to offer better protection and can actually control spider mites, especially if applied when populations are low. Neem oils and other oils have been found to increase the efficacy of neem insecticides while removal of neem oil reduced efficacy (Stark and Walter, 1995). The researchers found neem oil and other oils to increase the efficiency of insecticides, while working on pea aphid. Oils have also been reported to have direct mortality effects on mites (Agnello *et al.*, 1994). The effects of oils in increasing efficacy and mortality of mites could explain the better performance of Neemroc and Neem + Corn. Similar observations were obtained by Sun, (1968), Chinaella and Rovesti, (1992), Sanguanpong and Schmutterer (1992), who confirmed the effectiveness of neem oils and other oils. The increased efficacy caused by oils is believed to be mediated by increased penetration

and persistence of pesticides into crops and pests when directly applied (Treacy *et al.*, 1986 and 1991).

Neem extracts have been reported to have different components with insect pest antifeeding and antioviposition properties (Isman *et al.*, 1991). Azadirachtin, salanin, meliantriol and nambin have been reported as the most significant limonoids (BOSTID, 1992). Azadirachtin appears to cause 90% disruption of most pests, but does not kill insects immediately. It instead repels and disrupts their growth and reproduction (Schmutterer and Ascher, 1984). In the current study, Achook that has the highest content of azadirachtin was not effective in control of the mites, thus contradicting the above explanation. Ineffectiveness of Achook may be supported by the work of Sundaran and Sloane (1995), who observed that azadirachtin, the most effective insecticidal component of the neem tree is not very active against spider mites. Sanguanpong and Schmutterer, (1992), also obtained similar results regarding the effectiveness of azadirachtin on spider mites. High mite populations observed in this study in the biopesticides-treated plots could have been due to the short persistence and fast degradation of the biopesticides under natural environmental conditions (Koul *et al.*, 1989). Lowery and Isman (1996) reported limited persistence of 3 to 7 days for neem products.

GC- mite had low control over spider mites in both the greenhouse and field experiments. This result was consistent with laboratory experiments carried out in this study, which showed GC- mite to cause low mortality of spider mites. Similar findings have been shown by Boyd Jr. and Alverson (2000), who found extracts from garlic not to be effective on two spotted spider mites, although they were effective against other arthropods. Garlic extracts affected eggs of the spider mites, but not the

motile stages (Madanlar *et al.,* 2000). This phenomenon may also explain the low mortality caused by GC- mite in the experiments on motile stages.

The synthetic acaricide (Omite), which is a propargite, was the most effective in the control of red spider mites in the greenhouse and both field experiments. It reduced the population to zero level almost throughout the experimental period. These findings are in agreement with other works that have shown propargite to have effective ovicidal and adulticidal activity on spider mites (Jensen and Mingochi, 1988; Blair, 1989; Walsh et al., 1996). Although Omite was effective in controlling mites, its use may be short-lived, because Tetranychids are known to develop resistance to acaricides within a short period. An example is *T. urticae* that has developed resistance to 72 pesticides (Whalon and Mota-Sanchez, 2000).

b) Leaf damage index

Leaf damage caused by spider mites was lower in greenhouse experiments than in both field experiments prior to treatments. In the current study, lower leaf damage was observed in plots treated with Neemroc, Neem + Corn and Omite, especially in the first field experiment after the treatments were administered. Similar findings have been reported by Kashenge (1999), who found Neemroc effective in reducing the number of mites as well as lowering the feeding damage of *T. urticae* in greenhouse tomatoes.

Leaf damage by spider mites on tomatoes in the second field experiment was low and did not increase for all the treatments until the fourth week, unlike in the first field experiment. This result may have been due to differences in weather conditions during the two experiments. The first field experiment was conducted during the hottest months, in December, January and February, when the mean maximum

temperatures were 25.1°C. The second experiment was conducted during the coolest months in June, July and August with mean maximum temperatures of 22.4°C (Jaetzold and Schmidt, 1983; Metrological Dept. Kabete, 2003). Spider mites are normally active within a temperature range of 16-37°C and flourish at relatively low humidity. Moutia (1958) reported that hot and dry conditions favour the build up of mite populations, while heavy rain causes a sharp decline. This observation may explain the differences in damage in the two field experiments. It is worth also to mention that during the second trial, the rain had a positive effect in reducing leaf damage.

c) Phytotoxicity

All the neem-based biopesticides were phytotoxic to tomato plants. Phytotoxicity of neem-based pesticides has been reported several times by different authors. Unpublished work of Knapp and Varela found 1.5% Neemroc to be phytotoxic to roses grown in the greenhouse. Mansour and Ascher (1983) also reported phytotoxicity of extracts of neem seed kernels prepared from various solvents on bean leaf discs. Schmutterer (1995) confirmed neem oil was phytotoxic to plants.

d) Yields

The marketable yield of tomatoes in this study did not differ significantly in all the treatments for greenhouse and field experiments. The highest yields obtained were 500g per plant (18.5 ton/ha), 450g per plant (17 tons/ha) and 870g per plant (32 tons/ha) for the greenhouse, first and second field experiments, respectively. Lower yields than those obtained in this study have been reported in eastern Africa. Swai

(1995) reported average yield of 7 tons/ha in Tanzania, and Mwaule (1995) reported average yield of 10 ton/ha in Uganda. Higher yields than those obtained in this study have also been reported. Varela (1995) reported average yields of 100 tons/ha from commercial farms in Zimbabwe.

Lower yields obtained in the first field experiment could be attributed to high leaf damage (average of 3.0) prior to treatments. The damage was already done and plants could not compensate, even after the treatments. This may have reduced the photosynthetic area of the plants, thus affecting the yield. *T. evansi* can cause a yield loss of 90% (Saunyama, unpublished). Hussey and Scopes (1985) fixed the critical threshold at mean LDI of 2.0 as per their scale (also used in this study). Stacey (1983) found that removal of 50% of foliage reduces yield by 16%. This may support the low yields obtained in this study. In the second field experiment, mite infestation might have started too late, therefore less damage and hence higher yields.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

It is evident from the current study that there is a potential for using biological pesticides in the control of *T. evansi*, a newly introduced pest in Kenya that damages tomatoes. Although the botanical pesticides were not as effective as the synthetic acaricide it is worth mentioning that some of the neem-based pesticides namely Neem + Corn and Neemroc caused high mortality, especially where they were sprayed directly on the spider mites. The laboratory bioassays for all the biopesticides produced very low mortalities, including rates recommended by manufacturers, compared to the synthetic acaricide. More studies may be required to look into the effects of the biopesticides on egg-laying, egg-hatching and long-term survival of *T. evansi.* Such studies will provide additional basis for recommendation of the biopesticides in the control of this mite species.

All the pesticides tested produced very strong repellence of the spider mites. This result means that, the pesticides can be used as repellants in the control of mites. Biopesticides also exhibited very low residual action in the control of *T. evansi.* More studies are required to expose mites to the residues of biopesticides for longer periods to determine if the mortality will increase.

Greenhouse and field experiments carried out in the current study supported findings from the laboratory experiment in which the potential of using neem-based biopesticides in the control of *T. evansi* was evident. Achook and GC- mite were, however not effective in mite control. Since these two biopesticides are registered for mite control in Kenya, it may be necessary to carry out more field experiments in

different ecological zones to ascertain these finding and thus exclude them in the control of this mite species if found equally poor. It should be noted that Tetranychids are known to develop resistance to acaricides, within a short period of time. Studies may be required to investigate the possibility of *T. evansi* developing resistance to the biopesticides, as well as to the synthetic acaricide.

Some research findings have shown neem formulations to be toxic to the predatory mite (*Phytoseiulus persimilis* Athias-Henriot) deutonymphs. It may be necessary to investigate the effect of biopesticides and the synthetic acaricide tested in the present study on natural enemies before recommending their use in biological or integrated pest management of spider mites.

Leaf damage by spider mites in the second field experiment was lower than that in the first experiment. Since the two trials were carried out during two different seasons, (December to April, and July to November), it may be necessary to carry out more field experiments to confirm the effects of weather conditions on damage caused by the mites.

In the present study, neem-based products were phytotoxic and their use may be limited to crops that do not incur phytoxicity. Lower concentrations may also be experimented to establish if they cause phytotoxicity on crops and thus recommend their use in pest management if they prove safe.

The greenhouse and field experiments did not result in yield differences. This may be attributed to the fact that the experiments were designed mainly to investigate effects of pesticides on pest populations. Consequently, treatments were delayed until high infestation occurred. To accurately determine the effect of spider mites on yield, it can be recommended that experiments be designed and conducted specifically for the purpose of determining yield loss caused by this mite species. For instance, early

administration of treatments before mites cause damage should be investigated to determine mite effects on tomato yields.

It can be concluded that there is potential of using biopesticides, particularly the neem-based formulations in the control of spider mites on tomatoes. Although not as effective as the synthetic acaricide, neem-based biopesticides can be included in modern pest management programmes, where use of synthetic pesticides is undesirable or is restricted.

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APPENDICES

Appendix 1. Analysis of variance of mortality data of *T. evansi* exposed to different concentrations of biopesticides (see Table 2).

a). Achook 72 h

Source	DF	SS	MS	F Value	P
Concentration	4	1377.1	344.3	4.1	0.01
Error	25	2098.0	83.9		
Corrected Total	29	3475.1			

b). Neemroc 72 h

Source	DF	SS	MS	F Value	P
Concentration	4	3411.8	853.0	14.9	0.0001
Error	25	1433.7	57.3		
Corrected Total	29	4845.5			

c). Neem & Corn 72 h

Source	DF	SS	MS	F Value	P
Concentration	4	5038.7	1259.7	12.0	0.0001
Error	25	2621.3	104.9		
Corrected Total	29	7660.0			

d). GC- mite 72 h

Source	DF	SS	MS	F Value	P
Concentration	4	3147.4	786.8	4.9	0.005
Error	25	4025.4	161.0		
Corrected Total	29	7172.8			

e). Omite 72 h

Source	DF	SS	MS	F Value	P
Concentration	4	3975.3	9938.6	205.1	0.0001
Error	25	1207.7	48.3		
Corrected Total	29	40962.0			

f). Achook 96 h

Source	DF	SS	MS	F Value	P
Concentration	4	3831.9	957.9	12.3	0.0001
Error	25	1942.6	77.7		
Corrected Total	29	5774.5			

g). Neemroc 96 h

Source	DF	SS	MS	F Value	P
Concentration	4	10124.9	2531.2	48.5	0.0001
Error	25	1305.7	52.2		
Corrected Total	29	11430.6			

h). Neem & Corn 96 h

Source	DF	SS	MS	F Value	P
Concentration	4	11414.8	2853.7	58.8	0.0001
Error	25	1214.3	48.6		
Corrected Total	29	12629.1			

i). GC- mite 96 h

Source	DF	SS	MS	F Value	P
Concentration	4	5699.1	1424.8	14.3	0.0001
Error	25	2492.9	99.7		
Corrected Total	29	8192.2			

j). Omite 96 h

Source	DF	SS	MS	F Value	P
Concentration	4	41234.8	10308.7	344.4	0.0001
Error	25	748.3	29.9		
Corrected Total	29	41983.0			

Appendix 2. Analysis of variance of repellence of pesticides on *T. evansi* (see Figure 2)

a). 6 h

Source	DF	SS	MS	F Value	P
Treatment	5	37214.9	7443.0	36.9	0.0901
Error	48	9682.9	201.0		
Corrected Total	53	46897.8			

b). 24 h

Source	DF	SS	MS	F Value	P
Treatment	5	35372.2	7074.4	27.2	0.0001
Error	48	12487.5	260.2		
Corrected Total	53	47859.7			

c). 48 h

Source	DF	SS	MS	F Value	P
Treatment	5	35570.4	7114.1	29.5	0.0001
Error	48	11560.2	240.8		
Corrected Total	53	47130.5			

Appendix 3. Analysis of variance of residual effect of pesticides on *T. evansi* (see Figure 3).

a). 1 h

Source	DF	SS	MS	F Value	P
Treatment	5	42753.4	8550.7	369.9	0.0001
Error	30	693.5	23.1		
Corrected Total	35	43446.9			

b). 24 h

Source	DF	SS	MS	F Value	P
Treatment	5	45593.11	9118.6	495.1	0.0001
Error	30	552.5	18.4		
Corrected Total	35	46145.6			

c). 48 h

Source	DF	SS	MS	F Value	P
Treatment	5	47777.2	9555.4	927.6	0.0001
Error	30	309.0	10.3		
Corrected Total	35	48086.2			

d). 72 h

Source	DF	SS	MS	F Value	P
Treatment	5	36560.1	7312.0	588.9	0.0001
Error	30	360.2	12.4		
Corrected Total	35	36920.2			

Appendix 4. Analysis of variance of contact effect of pesticides on adults of *T. evansi* (see Figure 4)

a). 24 h

Source	DF	SS	MS	F Value	P
Treatment	5	32921.3	6584.3	53.3	0.0001
Error	30	3707.8	123.6		
Corrected Total	35	36629.1			

b). 48 h

Source	DF	SS	MS	F Value	P
Treatment	5	29848.2	5969.6	24.5	0.0001
Error	30	7297.7	243.3		
Corrected Total	35	37145.9			

c). 72 h

Source	DF	SS	MS	F Value	P
Treatment	5	34567.8	6913.6	24.2	0.0001
Error	30	8555.4	285.2		
Corrected Total	35	43123.2			

d). 96 h

Source	DF	SS	MS	F Value	P
Treatment	5	40255.6	8051.1	29.2	0.0001
Error	30	8259.6	275.3		
Corrected Total	35	48515.3			

Appendix 5. Analysis of variance of contact effect of pesticides on Larvae of *T. evansi* (see Figure 5)

a). 24 h

Source	DF	SS	MS	F Value	P
Treatment	5	10386.3	2077.3	13.7	0.0001
Error	30	4543.9	151.5		
Corrected Total	35	14930.2			

b). 48 h

Source	DF	SS	MS	F Value	P
Treatment	5	38594.3	7718.9	50.1	0.0001
Error	30	4618.8	154.0		
Corrected Total	35	43213.1			

c). 72 h

Source	DF	SS	MS	F Value	P
Treatment	5	40667.0	8133.4	42.6	0.0001
Error	30	5733.1	191.1		
Corrected Total	35	46400.1			

d). 96 h

Source	DF	SS	MS	F Value	P
Treatment	5	29428.1	5885.6	11.6	0.0001
Error	30	15218.5	507.3		
Corrected Total	35	44646.6			

Appendix 6. Analysis of variance on effects of pesticides on number of red spider mites on greenhouse tomatoes (see Figure 6).

a). Week 1

Source	DF	SS	MS	F Value	P
Treatment	5	4.2	0.9	1.2	0.36
Error	12	8.3	0.7		
Corrected Total	17	12.5			

b). Week 3

Source	DF	SS	MS	F Value	P
Treatment	5	1.7	0.3	1.4	0.30
Error	12	3.0	0.2		
Corrected Total	17	4.7			

c). Week 5

Source	DF	SS	MS	F Value	P
Treatment	5	115.9	23.2	4.6	0.01
Error	12	60.7	5.6		
Corrected Total	17	176.5			

d). Week 7

Source	DF	SS	MS	F Value	P
Treatment	5	468.6	93.7	5.0	0.11
Error	12	226.4	18.9		
Corrected Total	17	695.0			

e). Week 9

Source	DF	SS	MS	F Value	P
Treatment	548.2	109.6	0.9	7.2	0.003
Error	183.7	15.3	0.7		
Corrected Total	731.9				

f). Week 11

Source	DF	SS	MS	F Value	P
Treatment	5	149.3	29.9	2.2	0.12
Error	12	159.9	13.3		
Corrected Total	17	309.2			

Appendix 7. Analysis of variance of leaf damage by red spider mites on greenhouse – grown tomatoes (see Figure 7).

a). Week 1

Source	DF	SS	MS	F Value	P
Treatment	5	0.3	0.5	1.4	0.82
Error	12	0.4	0.1		
Corrected Total	17	1.7			

b). Week 3

Source	DF	SS	MS	F Value	P
Treatment	5	1.6	0.3	1.7	0.21
Error	12	2.2	0.2		
Corrected Total	17	3.8			

c). Week 5

Source	DF	SS	MS	F Value	P
Treatment	5	17.7	3.5	3.2	0.05
Error	12	13.5	1.1		
Corrected Total	17	31.1			

d). Week 7

Source	DF	SS	MS	F Value	P
Treatment	5	26.8	5.4	6.9	0.003
Error	12	9.3	0.8		
Corrected Total	17	36.1			

e). Week 9

Source	DF	SS	MS	F Value	P
Treatment	548.2	24.1	4.8	14.1	0.0001
Error	183.7	15.34.1	0.3		
Corrected Total	731.9	28.2			

f).Week 11

Source	DF	SS	MS	F Value	P
Treatment	5	20.1	4.0	1032.1	0.0001
Error	12	0.1	0.004		
Corrected Total	17	20.0			

Appendix 8. Analysis of variance on effects of pesticides on number of red spider mites on field-grown tomatoes in the first experiment (see Figure 8).

a). Week 1

Source	DF	SS	MS	F Value	P
Treatment	4	2962.2	740.5	4.6	0.02
Block	3	1614.3	538.1	3.4	0.05
Error	12	1930.3	160.9		
Corrected Total	19	6506.8			

b). Week 2

Source	DF	SS	MS	F Value	P
Treatment	4	1369.4	342.3	4.0	0.02
Block	3	309.2	103.1	1.2	0.34
Error	12	1022.6	143.2		
Corrected Total	19	2701.1			

c). Week 3

Source	DF	SS	MS	F Value	P
Treatment	4	1411.2	352.7	2.5	0.10
Block	3	496.4	165.5	1.2	0.37
Error	12	1718.6	143.2		
Corrected Total	19	3626.1			

d). Week 4

Source	DF	SS	MS	F Value	P
Treatment	4	17469.9	4367.5	6.5	0.005
Block	3	1779.2	593.0	0.9	0.47
Error	12	8036.3	669.7		
Corrected Total	19	27285.3			

f). Week 5

Source	DF	SS	MS	F Value	P
Treatment	4	207597.3	51899.3	7.1	0.004
Block	3	28282.9	9427.0	1.3	0.32
Error	12	87903.1	7325.3		
Corrected Total	19	323783.4			

g). Week 6

Source	DF	SS	MS	F Value	P
Treatment	4	478022.4	119505.6	19.3	0.0001
Block	3	52818.4	17606.1	2.9	0.082
Error	12	74182.3	6181.9		
Corrected Total	19	605023.1			

h). Week 7

Source	DF	SS	MS	F Value	P
Treatment	4	82791.1	206977.8	3.1	0.06
Block	3	6104.8	2034.9	0.3	0.82
Error	12	80424.9	6702.1		
Corrected Total	19	169320.0			

Appendix 9. Analysis of variance of leaf damage by red spider mites on field-grown tomatoes in the first experiment (see Figure 10)

a). Week 1

Source	DF	SS	MS	F Value	P
Treatment	4	0.16	0.04	1.0	0.46
Block	3	0.96	0.03	8.0	0.005
Error	12	0.48	0.04		
Corrected Total	19	1.60			

b). Week 2

Source	DF	SS	MS	F Value	P
Treatment	4	2.78	0.69	6.4	0.005
Block	3	0.48	0.16	1.5	0.27
Error	12	1.30	0.11		
Corrected Total	19	4.56			

c). Week 3

Source	DF	SS	MS	F Value	P
Treatment	4	12.62	3.15	24.9	0.0001
Block	3	0.31	0.10	0.8	0.51
Error	12	1.52	0.13		
Corrected Total	19	14.44			

d). Week 4

Source	DF	SS	MS	F Value	P
Treatment	4	29.44	7.36	102.6	0.0001
Block	3	0.39	0.13	1.8	0.19
Error	12	0.86	0.07		
Corrected Total	19	30.70			

e). Week 5

Source	DF	SS	MS	F Value	P
Treatment	4	26.60	6.65	118.6	0.0001
Block	3	0.16	0.05	1.0	0.44
Error	12	0.67	0.56		
Corrected Total	19	27.43			

f). Week 6

Source	DF	SS	MS	F Value	P
Treatment	4	38.64	9.67	1136.5	0.0001
Block	3	0.03	0.01	1.0	0.43
Error	12	0.10	0.01		
Corrected Total	19	38.77			

g). Week 7

Source	DF	SS	MS	F Value	P
Treatment	4	30.26	7.56	15129.0	0.0001
Block	3	0.002	0.0005	1.0	0.43
Error	12	0.006	0.0005		
Corrected Total	19	30.27			

Appendix 10. Analysis of variance of marketable tomato yield in the first experiment (see Table 4)

Source	DF	SS	MS	F Value	P
Treatment	4	0.02	0.004	0.47	0.76
Block	3	0.29	0.10	10.84	0.001
Error	12	0.11	0.01		
Corrected Total	19	0.41			

Appendix 11. Analysis of variance on effects of pesticides on number of red spider mites on field-grown tomatoes in the second experiment (see Figure 9)

a). Week 1

Source	DF	SS	MS	F Value	P
Treatment	5	937.4	187.5	1.4	0.27
Block	3	421.3	140.4	1.0	0.39
Error	15	1965.4	131.0		
Corrected Total	23	3324.1			

b). Week 2

Source	DF	SS	MS	F Value	P
Treatment	5	2863.0	572.6	2.0	0.14
Block	3	2359.3	786.4	2.7	0.08
Error	15	4399.5	293.3		
Corrected Total	23	9621.8			

c). Week 3

Source	DF	SS	MS	F Value	P
Treatment	5	21685.6	4337.1	14.3	0.0001
Block	3	1454.5	484.5	1.6	0.23
Error	15	4537.8	302.5		
Corrected Total	23	27677.9			

d). Week 4

Source	DF	SS	MS	F Value	P
Treatment	5	50248.0	10049.6	15.6	0.0001
Block	3	3620.1	1206.7	1.9	0.18
Error	15	9683.5	645.6		
Corrected Total	23	63551.6			

e). Week 5

Source	DF	SS	MS	F Value	P
Treatment	5	127035.4	25407.1	16.4	0.0001
Block	3	27963.0	9321.0	6.0	0.007
Error	15	23287.1	1552.5		
Corrected Total	23	178285.5			

f). Week 6

Source	DF	SS	MS	F Value	P
Treatment	5	359182.6	71836.5	33.9	0.0001
Block	3	16396.4	5465.5	2.6	0.09
Error	15	31822.8	2121.45		
Corrected Total	23	407401.7			

g). Week 7

Source	DF	SS	MS	F Value	P
Treatment	5	233865.6	46773.1	7.3	0.001
Block	3	24530.1	8176.7	1.3	0.32
Error	15	96604.9	6440.3		
Corrected Total	23	355000.6			

Appendix 12. Analysis of variance of leaf damage by red spider mites on field-grown tomatoes in the second experiment (see Figure 11).

a). Week 1

Source	DF	SS	MS	F Value	P
Treatment	5	0.53	0.11	0.8	0.58
Block	3	0.72	0.24	1.8	0.20
Error	15	2.06	0.14		
Corrected Total	23	3.31			

b). Week 2

Source	DF	SS	MS	F Value	P
Treatment	5	2.37	0.47	1.4	0.29
Block	3	0.25	0.08	0.2	0.86
Error	15	5.20	0.35		
Corrected Total	23	7.82			

c). Week 3

Source	DF	SS	MS	F Value	P
Treatment	5	4.62	0.92	3.4	0.03
Block	3	1.35	0.45	1.6	0.22
Error	15	4.12	0.27		
Corrected Total	23	10.10			

d). Week 4

Source	DF	SS	MS	F Value	P
Treatment	5	20.28	4.14	5.3	0.005
Block	3	2.44	0.81	1.0	0.41
Error	15	11.77	0.78		
Corrected Total	23	34.88			

e). Week 5

Source	DF	SS	MS	F Value	P
Treatment	5	8.75	1.75	2.4	0.09
Block	3	6.67	2.22	3.0	0.3
Error	15	11.05	0.74		
Corrected Total	23	26.47			

f). Week 6

Source	DF	SS	MS	F Value	P
Treatment	5	12.63	2.53	5.7	0.004
Block	3	2.06	0.69	1.5	0.25
Error	15	6.71	0.45		
Corrected Total	23	21.39			

g). Week 7

Source	DF	SS	MS	F Value	P
Treatment	5	16.12	3.22	84.6	0.0001
Block	3	0.13	0.04	1.2	0.36
Error	15	0.57	0.38		
Corrected Total	23	16.82			

Appendix 13. Analysis of variance for yields of marketable tomatoes in the second experiment (see Table 5).

Source	DF	SS	MS	F Value	P
Treatment	5	0.12	0.02	0.9	0.52
Block	3	0.15	0.05	1.8	0.18
Error	15	0.42	0.03		
Corrected Total	23	0.69			

Appendix 14. Repellent effect of pesticides on *T. evansi* on tomatoes (see Figure 2)

Treatments	Repellence (%) ± SE [1]		
	6h	24h	48h
Achook	95.0 ± 2.2 ab	95.5 ± 2.5 a	94.6 ± 2.7 a
Neem & Corn	96.4 ± 2.8 a	95.8 ± 2.2 a	95.0 ± 2.7 a
Neemroc	95.5 ± 3.1 ab	89.4 ± 3.1 a	89.6 ± 8.3 a
GC- mite	80.3 ± 5.9 b	73.1 ± 5.8 b	75.3 ± 7.5 b
Omite	75.9 ± 5.8 b	61.0 ± 8.3 b	60.0 ± 8.3 b

[1] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

Appendix 15. Residual effect of pesticides on *T. evansi* on tomatoes (see Figure 3)

Treatments	Mortality (%) ± SE [1, 2]			
	1h	24h	48h	72h
Achook	14.6 ± 2.0 b	5.6 ± 2.3 bc	1.3 ± 1.3 b	1.3 ± 1.3 b
Neem & Corn	7.0 ± 1.7 b	8.4 ± 2.4 b	1.1 ± 1.1 b	1.1 ± 1.1 b
Neemroc	9.5 ± 3.1 b	6.1 ± 2.2 bc	2.2 ± 2.2 b	2.3 ± 1.5 b
GC- mite	8.5 ± 2.3 b	2.4 ± 1.5 bc	1.1 ± 1.1 b	1.1 ± 1.1 b
Omite	100.0 ± 0.0 a	100.0 ± 0.0 a	98.9 ± 1.1 a	93.9 ± 1.1 a
Control	1.0 ± 1.1 c	1.1 ± 1.1 c	0.0 ± 0.0 b	0.0 ± 0.0 b

[1] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).
[2] Percentage mortality data were Arcsine transformed before analysis but mean values in the table represent the actual percentage of mortality.

Appendix 16. Contact effect of pesticides on adults of *T. evansi* on tomatoes (see Figure 4)

Treatments	Mortality (%) ± SE [1,2]			
	24h	48h	72h	96h
Achook	16.5 ± 4.5 b	21.4 ± 3.2 b	30.4 ± 5.0 c	32.8 ± 5.5 c
Neem & Corn	29.0 ± 5.6 b	41.1 ± 7.1 b	61.3 ± 6.9 b	91.7 ± 5.8 b
Neemroc	24.9 ± 6.3 b	34.3 ± 12.0 b	51.8 ± 13.0 bc	54.4 ± 13.0 c
GC- mite	14.5 ± 4.5 b	29.5 ± 5.5 b	31.3 ± 4.9 c	54.2 ± 5.5 c
Omite	94.3 ± 2.8 a	94.3 ± 2.8 a	100.0 ± 0.0 a	100.0 ± 0.0 a
Control	0.0 ± 0.0 c	0.0 ± 0.0 c	0.0 ± 0.0 d	1.7 ± 1.7 d

[1] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).
[2] Percentage mortality data were Arcsine transformed before analysis but mean values in the table represent the actual percentage of mortality.

Appendix 17. Contact effect of pesticides on larvae of *T. evansi* on tomatoes (see Figure 5)

Treatments	Mortality (%) ± SE [1,2]			
	24h	48h	72h	96h
Achook	4.9 ± 2.4 c	19.7 ± 4.6 c	24.2 ± 5.4 c	35.4 ± 9.7 b
Neem & Corn	14.9 ± 2.4 b	77.7 ± 4.4 b	85.9 ± 5.3 b	82.7 ± 8.9 a
Neemroc	18.8 ± 3.6 b	60.5 ± 8.6 b	73.3 ± 8.2 b	71.8 ± 10.0 a
GC- mite	31.6 ± 8.5 b	59.4 ± 5.8 b	68.8 ± 7.4 b	85.0 ± 9.6 a
Omite	51.5 ± 7.5 a	98.8 ± 1.2 a	98.8 ± 1.2 a	100.0 ± 0.0 a
Control	1.3 ±1.3 c	2.8 ± 1.8 d	4.6 ± 3.3 d	10.3 ± 6.6 b

[1] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).
[2] Percentage mortality data were Arcsine transformed before analysis but mean values in the table represent the actual percentage of mortality.

Appendix 18. Effects of pesticides on *T. evansi* on tomatoes in the greenhouse (see Figure 6)

Treatment	Number of mites per cm^2 ± SE [1,2]					
	Pre-application	Post- application				
	Wk 1	Wk 3	Wk 5	Wk 7	Wk 9	Wk 11
Achook	0.6 ± 0.1a	1.0 ± 0.7a	3.0 ± 0.9ab	7.7 ± 3.7a	12.4 ± 4.1a	5.9 ± 1.8ab
Neem & Corn	1.0 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1bc	1.4 ± 0.8b	5.0 ± 1.8b	7.2 ± 2.3b
Neemroc	2.0 ± 0.9a	0.3 ± 0.1a	0.7 ± 0.2bc	1.3± 0.3b	4.9 ± 0.6b	7.5 ± 2.6b
GC- mite	1.3 ± 0.4a	0.5 ± 0.1a	4.0 ± 1.8ab	11. 4 ± 3.0a	10.2 ± 2.9a	8.7 ± 3.2ab
Omite	1.3 ± 0.6a	0.1 ± 0.1a	0.1 ± 0.0c	0.2 ± 0.2c	0.8 ± 0.6b	0.7 ± 0.1c
Control	0.5 ± 0.1a	0.8 ± 0.2a	7.2 ± 2.4a	13.0 ± 3.7a	17.5 ± 1.0a	2.4 ± 1.0a

[1] Data are means of 2 plants/plot sampled at the top, middle and lower sections of plants and replicated three times.
[2] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

Appendix 19. Effect of pesticides on leaf damage by *T. evansi* on greenhouse tomatoes (see Figure 7)

Treatment	Leaf damage score ± SE [1,2,3]					
	Pre-application	Post- application				
	Wk 1	Wk 3	Wk 5	Wk 7	Wk 9	Wk 11
Achook	1.1 ± 0.3a	2.2 ± 0.4a	3.0 ± 1.1a	3.4 ± 0.8ab	4.9 ± 0.1a	5.0 ± 0 .0a
Neem & Corn	1.1 ± 0.1a	1.9 ± 0.1a	1.8 ± 0.5b	2.5 ± 0.5bc	4.4 ± 0.2a	5.0 ± 0.0a
Neemroc	1.0 ± 0.1a	2.1 ± 0.3a	1.3 ± 0.1b	2.4 ± 0.1bc	4.3 ± 0.1a	5.0 ± 0.0a
GC- mite	0.9 ± 0.1a	2.0 ± 0.3a	3.4 ± 0.7a	3.8 ± 0.1ab	5.0 ± 0.0a	5.0 ± 0.0a
Omite	1.0 ± 0.3a	1.5 ± 0.1a	1.0± 0.2b	1.0 ± 0.5c	1.7 ± 0.8b	2.2 ± 0.1b
Control	0.8 ± 0.1a	2.5 ± 0.1a	3.5 ± 0.6a	4.9 ± 0.1a	5.0 ± 0.0a	5.0± 0.0a

[1] Visual damage rating score: 0 = no damage, 1 = 1-15%, 2 = 20-30%, 3 = 35-50%, 4 = 55-70% and 5 = 80-100% damage.
[2] Data are means of 2 plants/plot assessed at the top, middle and lower sections of plants and replicated three times.
[3] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

Appendix 20. Effects of pesticides on number of red spider mites on field tomatoes in the first trial (see Figure 8)

Treatment	Number of mites per 3 leaflets ± SE [1,2]						
	Pre-application	Post- application					
	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7
Achook	44 ± 1.1a	17 ± 10.7a	13 ± 8.5a	69 ± 23.9ab	225 ± 70.1a	350 ± 66.2a	154 ± 29.2a
Neem & Corn	32 ± 11.2ab	16 ± 7.7a	19 ± 3.5a	22 ± 11.4b	86 ± 33.3b	126 ± 23.9b	113 ± 26.0a
Neemroc	15 ± 5.5b	20 ± 3.6a	20 ± 9.5a	20 ± 7 5b	79 ± 14.0b	119 ± 21.9b	191 ± 60.3a
Omite	16 ± 4.7b	1 ± 0.3b	0.2 ± 0.1b	0.1 ± 0.1c	1 ± 0.4c	3 ± 0.7c	3 ± 0.6b
Control	12 ± 1.1b	25 ± 5.6a	24 ± 3.1a	75 ± 7.8a	287 ± 58.8a	415 ± 71.7a	148 ± 45.3a

[1] Data are means of 2 plants/plot sampled at the top, middle and lower sections of plants and replicated three times.
[2] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

Appendix 21. Effects of pesticides on number of red spider mites on field tomatoes in the second trial (see Figure 9)

Treatment	Number of mites per cm^2 ± SE [1,2]						
	Pre-application	Post- application					
	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7
Achook	23 ± 6.7a	36 ± 16.4a	93 ± 16.8a	117 ± 12.5a	167± 38.6a	244± 18.3b	245 ± 50.0a
Neem & Corn	25 ± 5.2a	24 ± 5.7a	55 ± 4.3a	63 ± 9.3b	99 ± 10.0b	197 ± 44.7b	268 ± 32.1a
Neemroc	22 ± 3.8a	33 ± 13.7a	48 ± 6.4a	57 ± 12.7b	80 ± 13.8b	120 ± 18.2c	156 ± 38.1a
GC- mite	22 ± 3.7a	21 ± 2.6a	60 ± 4.8a	119 ± 14.9a	201 ± 24.4a	243 ± 12.8b	270 ± 56.6a
Omite	35 ± 4.9a	6 ± 1.2b	2 ± 1.1b	1 ± 0.3c	1 ± 0.2c	5 ± 0.5d	6 ± 0.7b
Control	37 ± 8.6a	38 ± 3.6a	89 ± 11.5a	131 ± 21.9a	203 ± 43.5a	403 ± 34.5a	285 ± 43.6a

[1] Data are means of 2 plants/plot sampled at the top, middle and lower sections of plants and replicated three times.
[2] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

Appendix 22. Effect of pesticides on leaf damage by *T. evansi* on field tomatoes in the first trial (see Figure 10)

Treatment	Mean leaf damage score ± SE [1, 2, 3]						
	Pre- application	Post-application					
	Wk1	Wk2	Wk3	W4	Wk5	Wk6	Wk7
Achook	3.1 ± 0.2a	2.8 ± 0.1ab	3.6 ± 0.1ab	4.7 ± 0.1a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
Neem & Corn	3.3 ± 0.1a	2.6 ± 0.2abc	3.2 ± 0.1bc	3.6 ± 0.2b	4.3 ± 0.1b	5.0 ± 0.0a	5.0 ± 0.0a
Neemroc	3.1 ± 0.2 a	2.3 ± 0.2 bc	2.9 ± 0.2c	3.7 ± 0.2b	4.4 ± 0.2b	5.0 ± 0.0a	5.0 ± 0.0a
Omite	3 0 ± 0.1a	2.1 ± 0.1c	1.7 ± 0.1d	1.2 ± 0.1c	1.8 ± 0.1c	1.5 ± 0.1b	1.9 ± 0.1b
Control	3.0 ± 0.1a	3.1 ± 0.1a	4.0 ± 0.2a	4.4 ± 0.1a	4.8 ± 0.1a	5.0 ± 0.0a	5.0 ± 0.0a

[1] Visual damage rating score: 0 = no damage, 1 = 1-15%, 2 = 20-30%, 3 = 35-50%, 4 = 55-70% and 5 = 80-100% damage.

[2] Data are means of 3 plants/plot assessed at the top, middle and lower sections of plants and replicated three times.

[3] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).

Appendix 23. Effect of pesticides on leaf damage by *T. evansi* on field tomatoes in the second trial (see Figure 11)

Treatment	Mean leaf damage score ± SE [1, 2, 3]						
	Pre-application	Post- application					
	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7
Achook	1.3 ± 0.2a	2.1 ± 0.3a	2.5 ± 0.1a	4.1 ± 0.1a	3.7 ± 0.2a	4.8 ± 0.1a	4.9 ± 0.1a
Neem & Corn	1.6 ± 0.2a	1.7 ± 2.1a	2.1 ± 0.1a	2.8 ± 0.1a	3.4 ± 0.4a	4.1 ± 0.1a	4.4 ± 0.1b
Neemroc	1.3 ± 0.2a	1.5 ± 0.1a	2.2 ± 0.2a	3.4 ± 0.4a	3.6 ± 0.5a	3.9 ± 0.4a	4.3 ± 0.1b
GC- mite	1.1 ± 0.2a	1.5 ± 0.2a	2.4 ± 0.1a	3.8 ± 0.3a	4.1 ± 0.3a	4.5 ± 0.1a	4.7 ± 0.1ab
Omite	1.3 ± 0.2a	1.2 ± 0.2a	1.2 ± 0.3a	1.3 ± 0.5b	2.2 ± 0.7b	2.5 ± 0.3b	2.5 ± 0.1c
Control	1.3 ± 0.2a	2.0 ± 0.4a	2.5 ± 0.5a	3.8 ± 0.8a	3.6 ± 0.7a	4.2 ± 0.7a	5.0 ± 0.0a

[1] Visual damage rating score: 0 = no damage, 1 = 1-15%, 2 = 20-30%, 3 = 35-50%, 4 = 55-70% and 5 = 80-100% damage.

[2] Data are means of 3 plants/plot assessed at the top, middle and lower sections of plants and replicated three times.

[3] Within column means followed by the same letter are not significantly different at P= 0.05 (SNK test).