ECOLOGICAL STUDIES ON CUCUMBER (*CUCUMIS SATIVUS* L.) PEST SPECTRUM, YIELD LOSS ASSESSMENT AND POTENTIAL FOR USE OF NEEM PRODUCTS IN KENYA.

By:

Matoka Tom Charles Mboya
B Sc. Animal Production (Hons)
Egerton University

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Department Zoology
Kenyatta University
P. O. Box 43844
Nairobi – Kenya

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DECLARATION

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

Matoka Tom Charles Mboya

This thesis has been submitted for examination with our approval as supervisors.

Dr Callistus K. P. O. Ogol
Zoology Department
Kenyatta University
P. O. Box 43844
Nairobi – Kenya

Dr Sithanantham Srinivasan
International Centre of Insect
Physiology and Ecology
P. O. Box 30772
Nairobi

DEDICATION

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ABSTRACT

Cucurbit vegetable crops, especially cucumber (*Cucumis sativus* L.) offer a good potential for urban and export marketing in Kenya. The crop also shows a promise for commercial production in Eastern Africa while pests are reckoned as one of the major production constraints. There is very little published information on the range and relative importance of different pests on the crop and appropriate control measures in the region. Exploratory studies conducted from November 1998 to August 2000 at KISE, Nairobi and November 1998 to March 1999 at Kibwezi, Eastern province in Kenya brought to focus arthropods (pests and natural enemies) associated with cucumber. The major pests observed included the African melon ladybird beetle (*Epilachna chrysomelina* L.), three thrips species [*Thrips tabaci* (Lindeman), *Frankliniella schultzei* (Trybom) and *Mycterothrips* sp.] infesting cucumber leaves and flowers besides the melon fruit fly, *Dacus ciliatus* (Loew) that damages fruits through oviposition and larval feeding.

Associated with the pests was a range of natural enemies whose majority were predators mostly of aphids and whiteflies. Four hymenopteran parasitoids of aphids and *Charops* sp. on *Helicoverpa armigera* (Hübner) were also recorded. Predatory coccinellids were the most abundant besides a few surphids on aphids, anthocorids on thrips and reduviids on both whiteflies and aphids.

Substantial marketable yield loss was found to occur due to pests attacking at the reproductive stage (thrips causing flower fall and fruit flies

infesting fruits). Other pests such as white flies and aphids were common but their adverse effects on the crop yield were not so apparent.

Since farmers are expected to comply with the Maximum Residue Levels (MRLs), set for chemical pesticides used; they need safer alternatives to pest control. To fill in this gap, botanicals such as neem (*Azadirachta indica* A. Juss) provide a safer alternative option in an Integrated Pest Management (IPM) system, which formed the basis for testing the neem products on key pests of cucumber since they are also compatible with other pest control methods.

Marketable yield levels in plots which received chemical protection at the vegetative stage during the first and the second season (11.4 and 11.6kg/plot) were highly significantly different from the unsprayed (control) plots yield (10.4 and 10.7 kg/plot) at (P=0.001 and P=0.0001) respectively. Protection at the reproductive stage gave an average yield of 14.6kg, which was also significantly different from plots with protection throughout the entire crop life (15.0kg) (P=0.001). Yields attained under neem product protection compared favourably with the chemical insecticide (lambdacyhalothrin/dimethoate) protected plot yields. Neem products (powder and oil) protected plots gave 8.8 and 7.6kg/plot in season one and 9.8 and 6.2kg/plot of damage-free (marketable) fruits in season two which were statistically different at (P=0.0001), and were significantly different from Karate and non-protected (control) plot yields 10.8, 12.8kg and 3.8, 4.0kg respectively for seasons one and two at (P=0.001).

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CHAPTER 1:

1.0. GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

1.1.1. Global distribution and local production of cucurbits

Cucurbits have a world-wide distribution with different species and varieties adapted to different geographical regions (Tindall, 1986). The family cucurbitaceae consists of 90 genera and 750 species of which seven are common to both hemispheres (Tindall, 1986). Pursglove (1968) identified thirteen cultivated genera comprising of different species and cultivars. Though different species of cucurbits originated from different parts of the world, they are biologically similar (Hill, 1983; 1988).

In Kenya, cucumber is mainly grown in the Eastern, Central, Coast and Rift Valley provinces by smallholder farmers (HCDA, 1995). Irrigation - dependent large commercial farms grow the crop for urban/export market (HCDA, 1996). Cucurbits from Kenya are mainly exported to France, United Kingdom, Germany and Netherlands (HCDA, 1996). Urban consumption has also steadily increased over the last few years, thus providing a local market (HCDA, 1995; 1996). Cucumber is generally a tendril/vine climbing and rapidly growing vegetable crop. The locally available and commonly grown cucumber varieties include Ashley, London Long green and Palomar (Patel, 1987; HCDA, 1995). Ashley is a medium early maturing variety crop that grows fairly vigorously; it bears dark green fruits that are rather small measuring about 19-22cm; the fruit skin is generally warty and spined; it is known to be resistant to downy mildew and thus suited for warmer regions (Simlaw, 1999).

1.1.2. Urban/export vegetable production for income generation in Kenya

Kenya is emerging as a major producer of horticultural products for both local and export market in the East African region (Ouko, 1997). Urban/export vegetable cultivation is an important income generation source for smallholder farmers in Kenya. It is estimated that nearly 250,000 farm families earn significant income through cultivation and marketing of export vegetables (Ouko, 1997). This sector ranks third after tourism and tea in terms of foreign exchange earnings (HCDA, 1995; Ouko, 1997). Among the horticultural commodities exported between 1993 and 1995, vegetables and fruits together attained an average of about forty thousand tonnes a year and this contributed to about 60% by volume and 45% by value (HCDA, 1995). Vegetables exported during 1995-96 fiscal year was worth US $ 25 million, accounting for 35-40 % of the total horticultural export earnings (Sithanantham *et al.*, 1997). Among the vegetable crop produce exported during this period, french bean ranked first followed by snow pea, okra, chillies (capsicum), cucurbits (water melons, cucumber, squashes, bitter gourd and pumpkins) and eggplant (brinjal) in descending order of importance (Appendix 1). Large quantities of these are also consumed locally and are never recorded and reported (HCDA, 1995). The volume of vegetable export is bound to increase with the increasing demand (HCDA, 1995 and Hortec, 1996).

Since cucurbits are emerging as important income generating crops for a multitude of smallholder farmers in this region, it is important to understand the associated pest spectrum besides assessing the extent of yield loss caused by pests and identify natural enemies associated with the pests. To be able to provide pest control alternatives to relieve farmers from chemical pesticide reliance the efficacy of botanical products (neem) were evaluated. The present study focused on these aspects, using cucumber, *Cucumis sativus* L. as the model cucurbit crop.

1.2. LITERATURE REVIEW

1.2.1. Cucumber production requirements

Cucurbitaceous plants especially cucumber, prefer relatively warm/hot climates. Cucumber has a short growing season of about four months in warm environments (Veeraragavathatham *et al.*, 1998). Tropical and subtropical climate is a suitable environment for its growth at an elevation of up to 1500 m. above sea level (Tindall, 1986). Its optimal growth temperature range is 21-30°C (Tindall, 1986; Veeraragavathatham *et al.*, 1998).

It requires adequate soil moisture and when rainfall is inadequate, irrigation is necessary (Veeraragavathatham *et al.*, 1998). Irrigation increases the crop yield besides improving fruit quality and ensuring reliability and duration of fruit availability in the market (Veeraragavathatham *et al.*, 1998). Water stress contributes to a high incidence of nubs and reduced fruit length. It also causes rapid seed development and softening of internal tissues, thus reducing fruit quality (Veeraragavathatham *et al.*, 1998), though Ashley is slightly drought tolerant (Tindall, 1986).

Cucumber thrives in a wide variety of soils ranging from clay to sandy-loam, but grows best in well-drained fertile non-acidic loamy soils with a pH range of 6.0 - 7.5. Soil pH and temperature ranges greatly influence plant nutrient uptake (Veeraragavathatham *et al.*, 1998). Cultivar Ashley bears separate male and female flowers (monoecious), with the first flowers to form being male (Patel, 1987). Bees assist in pollination, thus making fruit set possible since the male and female flowers are usually separate (Tindall, 1986). Some cucumber cultivars are parthenocarpic (need no pollination) (Patel, 1987). Pollination of flowers in the crown area over a short period (1 - 2 days) results in a desired multiple fruit per plant and a range of harvestable fruit sizes (Patel, 1987).

1.2.2. Economic importance and utilisation of cucurbits

Cucurbits contribute to a large proportion of locally consumed (urban) and exported vegetables because of their nutritional value (FAO, 1972). The edible varieties are a prime source of vitamins and minerals in addition to carbohydrates, proteins and fats. Bitter gourd (karela) has been traditionally used as dewormer for children (FAO, 1972). Other cucurbit species provide useful fibres, mature rinds as pots, containers or cutlery. The fibrous material may be used for scouring, oil filtering, bathing, packing and insulation. Cucurbits improve water conservation besides soil fertility through the dead leaves and stems (Choudhury, 1967; FAO, 1972).

1.2.3. Constraints to cucurbit production and sources of yield loss

Generally, cucurbit production experiences various constraints such as high cost of agricultural inputs, unpredictable weather patterns, produce perishability, poor marketing infrastructure, high freight rates and equally important is the incidence of pests and diseases (HCDA, 1995). High humidity favours the flourishing of most cucurbit pests and diseases such as melon fly and powdery mildew respectively (Gatumbi, 1986).

1.2.4. Cucurbit diseases

Various diseases attack cucumber causing direct or indirect yield loss through reduction in quantity and/ or quality of yield. Depending on the type of disease attack, part or entire crop destruction may be witnessed (Singh, 1986). Most of the diseases are shared among different cucurbit species. A single organism may be a causal agent or different biological races of the same agent may attack various host species (Lemaire *et al.*, 1988). Seed decay and seedling blight resulting in poor stands are caused by fungal species such as *Phythium* sp. and *Rhizoctonia* sp. (Tunlid *et al.*, 1989; Wolffhechel and Funck, 1992). Root rot infestation is also caused by fungi like *Phythium, Phytophthora* and *Fusarium* (Wolffhechel and Funck, 1992). Fusarium wilt fungus attacks roots and grow in the water conducting vessels causing varied symptoms before the plant eventually dies. It is caused by

Fusarium oxysporum which has different biological races in different cucurbits (Dércole and Gennari, 1992; Lin *et al.*, 1996).

Verticilium wilt appears like Fusarium wilt but only differs by having a pronounced yellowing and crown leaf death and is caused by *Verticilium* species (Lin *et al.*, 1996). Anthracnose disease caused by *Collectotrichum* sp. has symptoms appearing as leaf lesions that eventually coalesce and rupture (Wei *et al.*, 1991). Powdery and Downy mildews caused by *Erysiphe polygoni* and *Perenospora cubensis* respectively are other important cucurbit diseases whose suppression can be achieved through biological agents like *Ampelomyces quisqualis* (Ces.) (Philip *et al.*, 1990). These mildews are generally characterized by abundant fungal growth on leaves (Lemaire *et al.*, 1988). All these diseases are known to reduce the potential for attaining maximum yields.

1.2.5. Spectrum of cucurbit pests

Cucumber has a wide spectrum of pests that include mainly arthropods and nematodes whose infestation occurrence differ during crop growth stages. The intensity and extent of damage by these pests vary with time of attack, part of plant attacked and duration of attack (Dent, 1994). A study carried out on cucumber in Laguna, Philippines showed that insect pests, pollinators, parasitoids, predatory and immigrant arthropods associated with cucumber are influenced by the phenological and physiological age of the plant. In general, arthropod population density tends to increase from seedling to vegetative and reproductive stages and then decrease as the plant senesce (Bergonia, 1993). A succession of pests from vegetative to fruiting stage is very common in many crops (Kumar, 1984).

1.2.5.1. Coleopteran pests

Spotted cucumber beetle, *Diabrotica undecimpuctata* (Mann) is yellowish green, with twelve conspicuous black spots, six on each wing and a black head. It is about 6mm long. It is also known as *D. duodecimpuctata howardi* (Barber) and its larva is referred to as 'southern corn rootworm' because it attacks maize (Metcalf, 1993). In cucurbits, the larvae damage seedling leaves and tender shoots just below the ground hence cause girdling. Adults defoliate leaves and gnaw stems (Metcalf, 1993). While feeding, they may transmit a bacterial pathogen *Erwinia tracheiphila* (Smith) which causes bacterial wilt on cucumber and also transmits Cucumber Mosaic Virus (CMV) on other cucurbitaceous plants (Hill, 1983).

Striped cucumber beetle, *Diabrotica trivittatum* (Mann) is similar to the spotted cucumber beetle in habit, life history, host plants and control measures except that its body has striped markings. It spreads both the bacterial wilt and cucumber mosaic virus (Metcalf, 1993). The beetle is also known by names such as *Diabrotica vittatum* (Fabricius), *Acalymma vittatum* (Fabricius), or *Acalymma trivittatum* (Mann) (Metcalf, 1993).

Red pumpkin beetle, *Aulacophora foveicollis* (Lucas) inflict severe damage in early crop growth stage. Insecticidal control of the pest especially through several applications is a common practice (Singh and Mashra, 1977; Dabi *et al.*, 1980; Mavi and Bajwa, 1985).

African melon ladybird, *Epilachna chrysomelina* F. is a dome shaped beetle measuring about 6 - 8mm long. It has black spots on a yellowish-brown background. Both larvae and adults skeletonize leaves and also gnaw stems and fruits. They defoliate leaf tissue between small veins and only a network is left intact and often also the upper epidermal surface (Hill, 1983). The adults are strong fliers and life cycle takes about 35 days in the African tropical region with five possible generations in a year (Tindall, 1986). The beetle is probably among the most damaging to egg plant and maize (De Pury, 1978).

1.2.5.2. Homopteran pests

The melon aphid, *Aphis gossypii* (Glover) and Green peach aphid, *Myzus persicae* (Sulzer) are yellowish-green to black, winged or wingless insects, of about 1-2mm long. Only the females usually occur and produce living young parthenogenetically (Owusu *et al.*, 1996). Both adults and nymphs attach to the leaf underside to suck cell sap thus causing leaf distortion and wilting. Outbreaks are common on young plants or plant parts during spells of dry weather when they drop honeydew on the upper leaf and fruit surface on which sooty moulds develop thus making fruits unattractive. Goff and Tissot (1932) suggested that production of winged aphids is brought about by crowding conditions that stimulate wing production meant to play a dispersal role to new environments during which they transmit Mosaic Virus in cucurbits (Nasser, 1994; Andotra *et al*., 1995).

Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) and Tobacco whitefly, *Bemisia tabaci* (Gennadius) adults have yellowish bodies that appear to have been dusted with a fine white powdery material (Tindall, 1986). On hatching from eggs, the flat, transparent nymphs settle on the leaf near the hatching point until they become adults. In both the tropical and temperate regions, varied forms/biotypes are known to occur (Nuessly and Perring, 1995).

The infested plants lack vigour, turn yellow, wilt and die. Attacked leaves are usually covered with a coating of honeydew, a glazed, sticky material on which a sooty mould fungus grows to cover foliage (Nuessly and Perring, 1995). The resulting indirect damage by sooty mould (*Cladosporium sphaerospermum*) reduces photosynthesis and respiration (Vet *et al*., 1980). Economic Damage Threshold (EDT) is dynamic and the number of whiteflies producing quantities of honeydew insufficient to cause damaging levels of sooty moulds is a crude estimate of ETD (Hussey and Bravenboer, 1971). Alternative host plants include both cultivated and wild plant species such as black nightshade (*Solanum* sp.) and burs (*Xanthium* sp.) (Sukhoruchenko *et al*., 1995).

1.2.5.3. Dipteran pests

1.2.5.3.1. Fruit flies

Tephritid flies mostly attack fruits. Fruit flies include *Dacus cucurbitae* Coq., *B. ciliatus* (Loew) and *D. dorsalis* Hendel. They generally have yellow, brown or black stripes or spots or a combination of both, in characteristic positions or with light or hyaline spots in a darker field (Yang *et al*., 1994). The females oviposit in living healthy plant tissues. The larvae can live and feed in stalks, leaves, fruits, flower heads or soft seeds (Doharey, 1983; Yang *et al*., 1994). On fruits they cause both internal and external damage.

During development, mature females lay eggs beneath skins of suitable hosts, especially in ripening or ripe fruits and vegetables (Wen, 1985). At completion of the third instar, their skins harden to form a puparium with an inactive fourth instar larva inside it, which eventually sheds skin, forming a pupa; pupation usually takes place in the soil (Liquido *et al*., 1990; Uchida *et al*., 1990). A few days after adult emergence, sexual maturity is attained and a new life cycle is begun (Iwahashi and Majima, 1986; Hibino and Iwahashi, 1989). Their sexual maturity, reproductive efficiency and longevity depends upon the post emergence period diet (Iwahashi and Majima, 1986).

Female flies oviposit on fruits at any stage of their development and the infested fruits produce brown resinous fluid (Wen, 1985). During development, infested fruits may show distortion and malformation. Highly infested fruits may drop prematurely (Yang *et al*., 1994). The flies may also attack other softer parts of the crop in absence of fruits and their seasonal abundance coincides with the stage of host plant development (Gupta and Verma, 1995).

1.2.5.3.2. Leafminers

Agromyzid leafminer (*Liriomyza* sp.) adults are small (1.5mm) black and yellow flies having a bright yellow scutellum. The larvae are tiny bright yellow maggots about 2mm long when they emerge from leaves to pupate. The first larval stage burrows into the mesophyll tissue where the second larval stage will remain to feed. The larvae mine between upper and lower leaf surfaces thus creating contorted winding whitish tunnels that are initially narrow and become wide as the larvae grow. Some mines may have continuous black trails of frass (Singh *et al*., 1992). The third larval stage concentrates its feeding towards the upper leaf surface and when it matures, it cuts a longitudinal slit in the leaf and exits to pupate on the leaf or ground surface. Pupae look like tiny brown grains of rice (Godfrey *et al*., 1997). Two distinct species, vegetable leafminer (*Liriomyza sativa* L.) and serpentine leafminer (*Liriomyza trifolii* Burgess) whose females insert oval eggs into punctured leaf tissues are known. Most punctures are feeding sites for adults who lap up exudate (Godfrey *et al*., 1997). Light infestations start early at cotyledonary leaf stage and when not controlled severe infestations develop late in the season causing plant death (Specer, 1973).

1.2.5.4. Lepidopteran pests

Cucurbit worms (*Diaphania* spp.) and fruit borer, (*Helicoverpa* spp.) are among the lepidopteran pests that infest cucurbits not only for mere association but, for sheltering, oviposition, feeding and development to adult stage. Oviposition and feeding preference for cucurbit species vary (Ke *et al.*, 1988). Noctuids and pyralids are known to be highly destructive to cucurbits. Three known destructive pyralid species include pickleworm, (*D. nitidalis* Stoll), melonworm (*D. hyalinata* L.) and gherkin fruit borer (*D. indica* Saunders) which have been reported to be highly destructive in south eastern United States (Fulton, 1947; Dilbeck *et al*., 1974). Pumpkin caterpillar (*Margaronia indica* (Saunders) and *D. nitidalis* Stoll larvae tunnel into flowers, buds, stalks, vines and fruits (Dilbeck and Canerday, 1968) and China (Ke *et al*., 1988). The melon worm usually confines its feeding to foliage but is occasionally found on flowers (Reid and Cuthbert, 1956). The larvae of gherkin fruit borer is known to feed on leaves, flowers, buds and fruits then pupate within leaf folds (Patel and Kuruvilla, 1956; Peter and David, 1992). *Diaphania* are known to be parasitized by *Trichogramma confusum* (*T. chlonis*) and families of parasitoids like Schenocharops, Apanteles and Elasmus (Ke *et al.*, 1988). Peter and David (1992) found that different cucurbit species as host plants had a profound influence on the level of parasitism of *D. indica* by *Apanteles taragamae* (Hymenoptera: Braconidae).

1.2.5.5. Thysanopteran pests

Tobacco/onion thrips -*Thrips tabaci* (Lindeman) and Flower thrips - *Frankliniella* sp. suck the sap from plant tissue (Harrewijn *et al.*, 1996). Polymorphic forms are known to occur (Sakimura, 1969). Plant nutrition with special preference to total aromatic acids (free and bound) influence resistance or susceptibility (Harrewijn *et al.*, 1996). Mollema and Cole (1995; 1996) found that high concentrations of aromatic amino acids in plant leaf proteins are important for thrips growth and development.

Thrips infest different plant species, both cultivated and wild at different growth stages (Ali *et al.*, 1987). Three broad categories attacking flowers, leaves and bulbs or corms are known to occur (Wang, 1987; Kogel *et al.*, 1997). Species attacking floral parts assist in pollination (Velayudhan *et al.*, 1985). Some species are known to transmit viral diseases such as Tomato spotted wilt virus (tospovirus or SWV) exhibiting damage symptoms as reported by Ullam *et al.* (1992) in groundnuts (Amin *et al.*, 1981; Reddy *et al.*, 1983), cucurbits (Kogel, 1995; 1996; 1997) and cotton (Bournier and Couilloud, 1969). Feeding damage causes malformation, tearing, browning and silvering of leaf surfaces (Bournier and Couilloud, 1969).

1.2.5.6. Non insect pests

Red spider mite, *Tetranychus urticae* (Koch) (Acarina: Tetranychidae) is a major glasshouse cucumber pest. It is bright orange in colour. Its counterpart in the tropics is *T. cinnabarinus* (Boisd), (Acarina: Tetranychidae). They damage plant leaves by feeding on cell chloroplasts thus causing depressions with yellowish marks. These fine speckles coalesce to form bronzed areas as their populations increase. Finally, leaves shrivel and die. When mite numbers become excessive, the individuals become negatively geotropic and migrate to the apical leaves. Here they congregate and leaf - tips bend under their weights from which they descend on silken 'ropes'. The feeding is usually concentrated along leaf veins and web spinning on the lower leaf surface (Hussey, 1969) which can be estimated through a Leaf Damage Index (LDI) (Hussey and Bravenboer, 1971).

1.3. RATIONALE AND HYPOTHESES OF THE STUDY

1.3.1. Rationale/Justification

Cucurbits are emerging as important income generating crops in Kenya for both urban and export markets. Due to their high profitability, production constraints such as pest and disease infestation alongside marketing bottle necks resulting from high pesticide use that pose human health risks are key factors to consider to improve the produce quality and marketability. Pest control in this crop has often involved heavy use of chemical pesticide sprays with the ultimate aim of reducing/minimizing damage and associated yield loss. Chemical control, although outside the realm of peasant agriculture, continues to be a common recommendation for insect pest control (Mensah, 1988). Besides high costs (Nangju *et al.*, 1979; Olowe *et al.*, 1987), increased adoption of insecticide - dependent pest control technology may harm agriculture and natural ecosystems in the long run (Olowe *et al.*, 1987). Possibility of target pests developing resistance to insecticides cannot be excluded from the issue of residual effects in marketable products like cucumber fruits eaten raw as salad (Beevi *et al.*, 1992). In light of this, it is important to assess, identify and record the range of arthropod pests attacking cucumber crop in the field. Since pests attack at different stages of crop growth, it was important to partition the effects of their attack so as to know which crop growth stage pest infestation was more severe based on the extent of avoidable loss caused. The current study on cucumber gave an indication of crop growth stage when protection is critical and so would assist in focusing on pest that attack the crop at that stage. The natural enemies associated with the cucumber pests needed to be also identified and documented to provide baseline information for future research to cater for their potential utility in biological control. Due to the concerns and limitations associated with pesticide use, interest has grown for use of safer alternative pest reduction means like cultural methods such as intercrops (Dissemond and Hindorf, 1990; Ampong-Nyarko *et al.*, 1994) and botanical extracts (Schmutterer, 1990) in combination with biological agents so as to minimise frequency of insecticide applications (Mensah, 1988). Botanical pest control is a traditional method with not so much of innovation and it is a return to an old approach with a new ecological understanding of environmentally friendly pest control measures for sustainable long-term food sufficiency (Saxena, 1989). The present study sought to evaluate the efficacy of two neem products so as to provide safer pest control alternatives to the farmers, since neem products are locally available, cheap and easy to prepare.

1.3.2. Hypotheses

(i) Cucumber crop is attacked by different pests whose populations are associated with naturally occurring biological control agents.

(ii) The occurrence of cucumber pests varies with plant growth stage that also influences the extent of avoidable yield loss.

(iii) There exists a potential to reduce pest infestation and damage on the crop through the use of plant derived products (botanicals) such as neem.

1.4. OBJECTIVES OF THE STUDY

1.4.1. General objective of the study

The broad objective of this study is to develop baseline information on the spectrum of arthropod pests, extent of avoidable yield loss, identification of natural enemies associated with the recorded pests and efficacy of the two neem products in controlling a few selected major cucumber pests.

1.4.2. Specific objectives of the study

(i) To identify cucumber arthropod pest spectrum and their potential natural enemies

(ii) To estimate extent of avoidable yield loss caused by pests attacking the crop at different growth stages

(iii) To evaluate the efficacy of neem products on major cucumber pests

CHAPTER 2:

2.0. MATERIALS AND METHODS

2.1. Sites description

The investigations were conducted at International Centre of Insect Physiology and Ecology (ICIPE) on its experimental field station at Kenya Institute of Special Education (KISE), and at the University of Nairobi's Institute of Dryland Research Development and Utilization (IDRDU) Kibwezi Farm. ICIPE station is 12 km North east of Nairobi at an altitude of 1940m above the sea level. It lies between latitude 1° 10' S and 1° 15' S; longitude 36° 50' E and 36° 55'E. The area is semi arid with a mean annual temperature of 25° C and experiences a bimodal rainfall distribution of 800 and 1100 mm annually for both the short and long rainfall maxima respectively (Lamba, 1994). The site at the Institute of Dryland Research Development and Utilization (IDRDU) Kibwezi is 200 km south east of Nairobi at an altitude of 700m above sea level. It lies between latitude 2° 21' S and 2° 25' S; longitude 38° 02' E and 38° 05'E. The area is arid with single rainfall maxima of less than 700 mm annually. The site is used for research and commercial horticultural production purposes and funded by the governments of Kenya and Israel on a collaborative basis. Both the trial sites, Kibwezi and KISE - Nairobi, represented lowlands and highlands respectively (Appendix 2).

2.2. Cucumber field trials for monitoring pest spectrum and assessment of yield loss

The experimental trials on the chemical application regime were conducted to assess cucumber pest spectrum and avoidable loss in yield due to pests attacking cucumber at the vegetative and reproductive stages. The trial was carried out at both sites between Nov. 1998 and Feb. 1999. This trial was repeated at the (KISE) site between November 1999 and March 2000. The second trial was aimed at assessing the efficacy of neem products in controlling the key pests. These trials set to evaluate neem products were conducted only at the first site (KISE), once during September 1999 - January 2000 and again during May – August 2000. Attempts to grow the trials at KISE during April – September 1999 were unsuccessful due to unforeseen problems in germination and irrigation resulting in poor plant stand.

Cucumber (*Cucumis sativus* L.) var. Ashley was planted at both sites. The plots measured 4m by 4m each separated from one another by a strip of 2m all round. Five seeds per hill were sown at inter and intra row spacing of 1.5m. A planting depth of between 2-2.5 cm was adopted (Patel, 1987). During the planting, a mixture of both organic farm-yard manure (F.Y.M) and inorganic diammonium phosphate, 18.5%N + 48% P_2O_5 (D.A.P) fertilizer were applied into the planting holes. The seedlings were observed to germinate after ten days.

Gapping was done on the thirteenth day after sowing by transplanting seedlings that were thinned from the other hills with good germination to those with poor gemination. Thinning was carried out on the hills to maintain only single healthy seedlings in each hill. Four weeks after planting, calcium ammonium nitrate, 23%N (CAN) was top-dressed at a rate of 10g per hill to boost vegetative growth and improve plant vigour. Plots were manually weeded twice in each season to reduce weed competition. The purpose of this experiment was to generate data on pest spectrum at different stages of cucumber crop and extent of yield loss due to pests. Different regimes of protection through insecticide application at two main growth stages – vegetative and reproductive - formed basis for the comparisons. There were four treatments as listed below replicated five times in a completely randomized block design (Fig. 1).

T_1 - Unsprayed cucumber crop (Control)

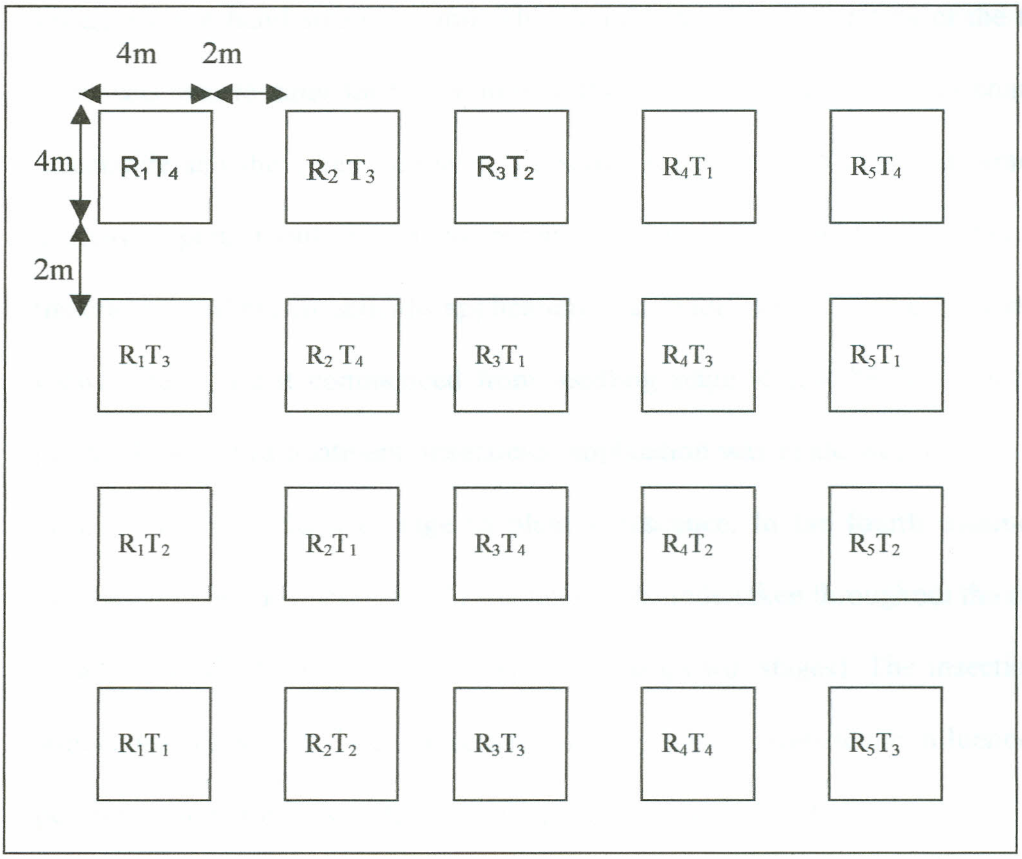
T_2 - Pesticidal protection at the vegetative stage

T_3 - Pesticidal protection at the reproductive stage

T_4 - Pesticidal protection at both the vegetative and reproductive stage

Nb: In treatments (T_2, T_3 and T_4) where pesticidal protection was offered, Karate (Lambdacyhalothrin) and (Rogor) Dimethoate were the chemical insecticides sprayed in alternate weeks.

Fig. 1: Cucumber chemical insecticide protection regime, experimental field plot layout



Two insecticides namely Lambdacyhalothrin (karate®) and Dimethoate (Rogor®/Roxion®) were applied in alternative weeks at a rate of 2ml/litre of water, using a hand sprayer pump. The alternate weekly application of the two chemicals was to cater for the control of the different pests, one being contact insecticide and the other with systemic action respectively. The first treatment, unsprayed plots (control) did not receive any insecticide application. Second treatment is where insecticide application was made weekly at the vegetative growth stage and it commenced from seedling stage to just before flowering period. In the third treatment, insecticide application was made weekly from the onset of the reproductive stage to plant senescence. In the fourth treatment, protection by weekly spraying of insecticide was undertaken throughout the crop growth span (both vegetative and reproductive growth stages). The insecticide application regimes in different treatments were to help estimate the influence of pest infestation during vegetative and reproductive stages on final yield.

2.3.1. Monitoring cucumber pest spectrum and infestation severity

The pest spectrum occurring on the unsprayed plots was monitored weekly. The infestation severity levels of aphids, whiteflies and leaf miners were scored on five randomly selected plants per plot at weekly intervals. To assess intensity of pest infestation and damage severity, sampling methods based on a relative severity ranking score (RSS); X - less severe, XX -moderately severe and XXX – severe suggested by Sutherland *et al.* (1996) were adopted. In addition, thrips infesting flowers were counted from ten randomly picked (both male and female flowers at the ratio of 1:1) per plot in alternative weeks. The flowers were preserved in vials half filled with 70% alcohol and the thrips numbers were counted under a dissecting microscope. Leaf beetles were directly counted on five randomly picked plants at weekly intervals. Whiteflies and aphids were estimated using population scores on a scale of 0 – 5 (Table 1). Leaf miners were estimated by scoring the intensity of freshly mined leaves on five randomly selected plants per plot. The rating was done on cotyledonary as well as true leaves on a scale of 0 – 5 (Table 1) (Odour *et al.*, 1998). For fruit flies, the numbers of larvae/pupae per fruit as an average of ten randomly selected infested fruits per plot was recorded each time harvesting was done, besides counting the proportion of fruit fly infested fruits among the total fruits harvested per plot.

Table 1: Rating scores for the major pests of cucumber recorded at KISE and Kibwezi

Pest group	Scoring rate	Rating interpretation
Whiteflies and aphids		**Pest numbers estimated per plant**
	0	None observed
	1	Up to10
	2	More than 10 up to 50
	3	More than 50 up to 100
	4	More than 100 up to 200
	5	More than 200
		Number of fresh mines per leaf
Leafminers	0	no fresh mine
	1	Up to 5
	2	More than 5 up to 10
	3	More than 11 up to 15
	4	More than 16 up to 20
	5	More than 21

2.3.2. Collection of associated natural enemies and identification of the arthropods

A number of natural enemies on different pests were collected/recovered from their hosts from the unsprayed plots at weekly intervals. These insects were either seen to predate on their prey or were recovered from the associated host insects. Most of the slow moving predators were hand- picked while the fast moving were sweep-netted. The parasitoids were recovered from their hosts which were kept alive through feeding on fresh stock of food while in the petri -dishes.

All the samples of arthropod pests and natural enemy collected from both the sites were preserved and sent through the Biosystematics Department of ICIPE to Kenya Plant Health Inspectorate Services (KEPHIS) at KARI (Kenya Agriculture Research Institute) and the National Museums of Kenya for identification. Thrips samples were sent to Agricultural Research Centre (ARC), South Africa for identification. The identifications were done based on conventional taxonomic characteristics (morphological and physiological features) of the collected arthropods.

2.3.3. Assessing crop yield and yield loss

All marketable sized fruits were harvested weekly from each plot by plucking them from vines. They were graded as "pest - damage free" (marketable)" and "pest damaged" fruits, counted and weighed using a scale balance. This was carried out in all the plots at different harvests. Fruits damaged by fruit flies alone were also counted and weighed separately and ten randomly selected fruits were later taken to the laboratory for dissection to record the number of larvae (maggots) and pupae. The yield loss during the vegetative and reproductive stages was estimated as the reduction in yield over the yield in plots that were protected at both stages.

2.4. Field evaluation of neem products

The aim of the experiment was to evaluate efficacy of the two neem products commercially available in Kenya in controlling any of the common pests on cucumber. The experiment consisted of four treatments listed below and replicated five times in a completely randomized block design (CRBD). The field trial layout and management was similar to that documented under the chemical protection regime trials (Section 2.2).

T_1 - No spray (Control)

T_2 - Karate /Dimethoate alternate spray (2ml/l)

T_3 - Neem oil spray (20ml/l)

T_4 - Neem powder spray (50g/l)

The two neem products (powder and oil) tested are manufactured by Saroc Company Limited. The neem seed cake powder (NSCP) known as (Neemros®) which contains 0.5% azadirachtin while neem oil (Neemroc®) extracted from the neem seed cake has azadirachtin content of 0.03%. The neem oil (Neemroc®) suspension of 0.03% azadirachtin was prepared by mixing 30ml of oil to a litre of water whereas (Neemros®) was prepared at a dosage of 50g/L. The data collection for insect infestation was limited to leafminers, whitefly, thrips, beetles and fruit flies and yield records were conducted similarly to that of yield loss experiment (section 2.3.3).

2.5. Statistical analysis

The collected data, scores and counts for arthropods together with fruit yield in weights and numbers were keyed into the computer using the Microsoft Excel 5.0/97. Fruit numbers were converted into percentages for yield comparison between the different treatments. Data on insect counts / scores were log transformed to standardize/ normalise their distribution. Analysis of variance (ANOVA) was performed on the data and the Student Newman Keul's (SNK) test was adopted as a post ANOVA test to rank the means of those that were statistically different (Sokal and Rohlf, 1981). The analysis was accomplished through SAS system version 3.12 of 1997.

CHAPTER 3:

3.0. RESULTS

3.1. Spectrum of arthropods associated with cucumber

The pest spectrum was similar at the two experimental sites KISE and Kibwezi. The recorded pests were broadly categorised into three main groups on relative severity status (RSS) (Table 2). Out of the three groups – sucking, chewing and mining, the miners/borers were fewer individual species, but often occurred in high densities/numbers on the crop (xxx). Chewing insects comprised of coleoptera and lepidoptera, out of which coleopterans were the majority and important pests that caused defoliation, with the most important being members of genus *Epilachna*. The three species of lepidoptera were noctuids, out of which *Agrotis* sp. was on of the highly destructive pests through cutting of the plant shoot just below the ground surface. Sucking pests were the second largest group comprising of six different families whose members scored high indices on the RSS rating with the largest group being the chewing insects. Fruit borers/miners were found to be commonly affecting the final produce (fruits). The Melon fruit fly, *Dacus ciliatus* (Loew), cause damage to the fruits through oviposition, feeding and development of the larvae. The larvae fed on tender and soft tissues whereas adults feed on juicy exudates/sap from the fruit. The overall severity/abundance of the different major pests was recorded and their incidence/occurrence from the cotyledonary to the late reproductive stage of the crop was recorded and is illustrated Fig. 2.

Table 2: Spectrum of arthropod pests infesting cucumber (at KISE and Kibwezi), Kenya, 1998 – 1999.

Common name	Scientific name	Family	Relative pest damage severity*	
Sucking pests			**KISE**	**Kibwezi**
Tobacco thrips	*Thrips tabaci* (Lindeman)	Thripidae	XXX	XXX
Flower thrips	*Frankliniella schultzei* (Trybom)	Thripidae	XXX	XXX
Thrips	*Mycteothrips* sp.	Thripidae	X	X
Leaf footed bug	*Leptoglossus membranaceus* (Fabricius)	Coreidae	XX	XX
Cotton stainer	*Dysdercus cardinalis* (Gerst)	Pyrrhocoridae	XX	XX
Green – house white fly	*Trialeurodes vaporariorium* (Westwood)	Aleyrodidae	XXX	XXX
Tobacco whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	XX	XX
Red spider mite	*Tetranychus urticae* (Koch.)	Tetranychidae	XX	XX
Cotton aphid	*Aphis gossypii* (Glover)	Aphididae	XX	XX
Green peach aphid	*Myzus persicae* (Sulzer)	Aphididae	XX	XX
Miners/borers				
Fruit borer	*Helicoverpa armigera* (Hübner)	Noctuidae	XX	XX
Melon fruit fly	*Dacus ciliatus* (Loew)	Tephritidae	XXX	XXX
Leaf miner	*Liriomyza* sp.	Agromyzidae	XXX	XXX

Table 2. Spectrum of arthropod pests infesting cucumber (at KISE and Kibwezi), Kenya, 1998 – 1999' continued.

Common name	Scientific name	Family	Relative pest damage severity*	
Chewing pests				
African melon lady bird beetle	*Epilachna chrysomelina* (Fabricius)	Chrysomelidae	XX	XX
Defoliating beetle	*Epilachna misella* (Weise)	Coccinelidae	XX	XX
Spotted cucumber beetle	*Diabrotica undecimpunctata* (Barber)	Chrysomelidae	XXX	XXX
Striped cucumber beetle	*Diabrotica trivittatum* (Fabricius)	Chrysomelidae	XX	XX
Red pumpkin beetle	*Aulacophora foveicollis* (Lucas).	Chrysomelidae	X	X
Defoliating beetle	*Casnoidea* sp.	Carabidae	X	X
Black shiny beetle	*Lagria villosa* (Fabricius)	Lagriidae	X	X
Termites	*Macrotermes* sp.	Termitidae	X	X
Cut worm	*Agrotis* sp.	Noctuidae	XX	XX
Caterpillar	*Plusia* sp.	Noctuidae	X	X
Caterpillar	*Leptaulaca fiscicollis* (Thorns)	Noctuidae	X	X

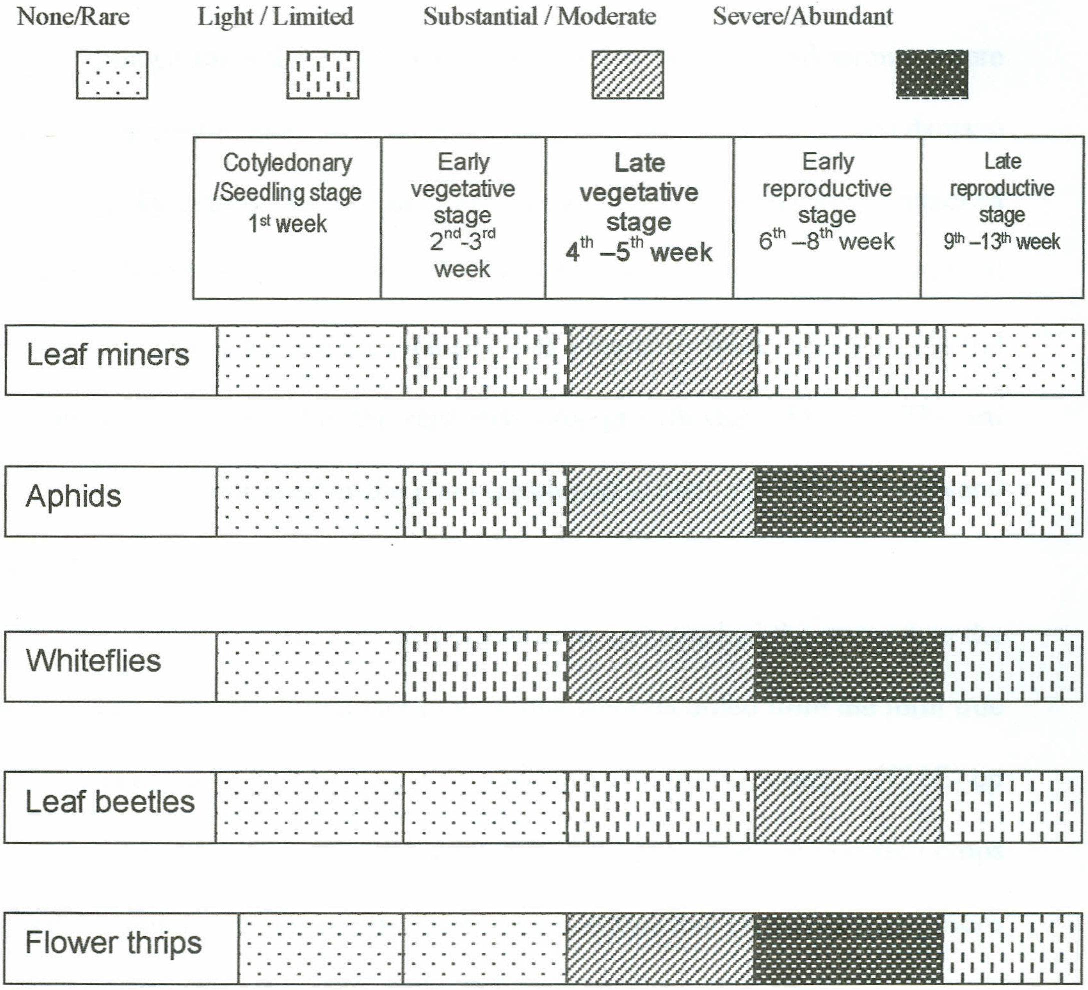
* Rated based on relative crop damage/severity

X - Less severe

XX - Moderately severe

XXX - Severe

Fig. 2: Illustration of relative population intensity/abundance of a few selected major pests on the different cucumber growth stages



3.2. Pest population abundance under pesticide protection regimes

3.2.1. Insect infestation observations

Amongst the arthropod pests, cutworms (*Agrotis* sp.) and termites were among the earliest to attack at the vegetative growth stage. They caused damage to seedlings by cutting shoots just below the ground level thus causing attacked plants to wilt and die. Infestation by leaf miners (*Liriomyza* sp.) was seen even at cotyledonary leaf stage and its intensity was greater in plots where no control measure was administered in the vegetative crop growth stage (Fig. 3a). The leaf miner infestation continued as the plant developed to form true leaves for several weeks (Fig. 3b).

Whiteflies (*Bemisia* sp. and *Trialuerodes* sp.) attacked the crop when the first true leaves formed but higher infestations were recorded from the forth true leaf stage (TLS) which coincided with the forth week after emergence (WAE) up to the seventh week (Fig. 4). The unsprayed (non-protected/unprotected) crops peaked in whitefly infestation on the 6^{th} week. After this peak, the populations gradually declined through to the eleventh week.

Almost a similar trend was recorded on the occurrence of the aphids, *Myzus persicae* (Sulzer) and *Aphis gossypii* (Glover). Aphid populations infesting cucumber crop from the first week after emergence to the eleventh week showed a gradual increase in their populations up to mid reproductive stage of the crop (Fig. 5). The non- protected/unprotected crops recorded increasing aphid populations with a short sharp rise from the forth week, plateauing between the fifth and sixth week then continued in a long steep gradient from the sixth to the eighth week and reached a peak score of 4.7 after which they declined. Those infesting the plots protected at the vegetative stage were relatively less severe initially in the first six weeks (1.0 score) and rapidly rose to 3.7 on the ninth week. The populations dwindled rapidly after this period through to the eleventh week. The crop protected at both the vegetative and reproductive stages and that protected at the reproductive growth stage alone maintained a low score of less than 1.0 and later tapered off towards the eleventh week.

Fig. 3a: Relative abundance of leafminers on cotyledonary leaves of cucumber under different chemical protection regimes

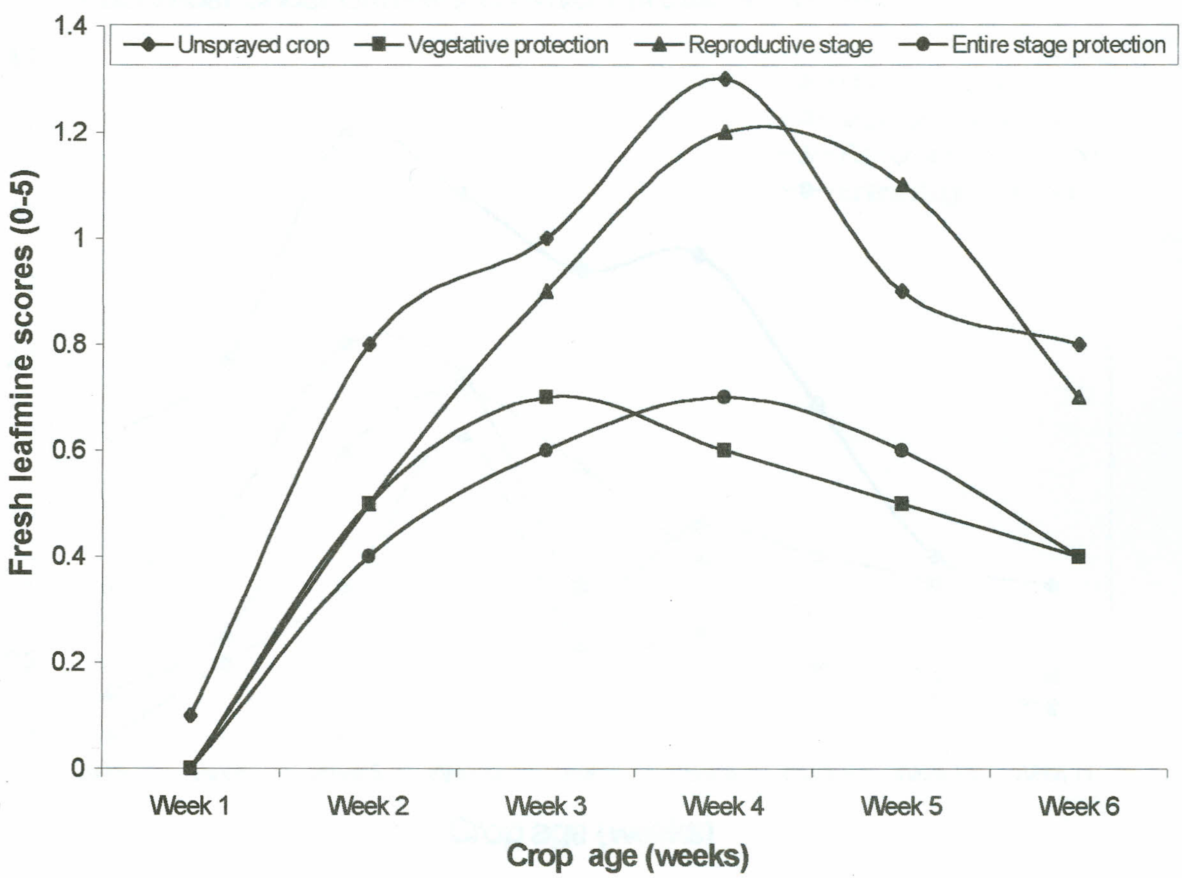


Fig. 3b: Relative abundance of leafminers on true leaves of cucumber under different chemical protection regimes

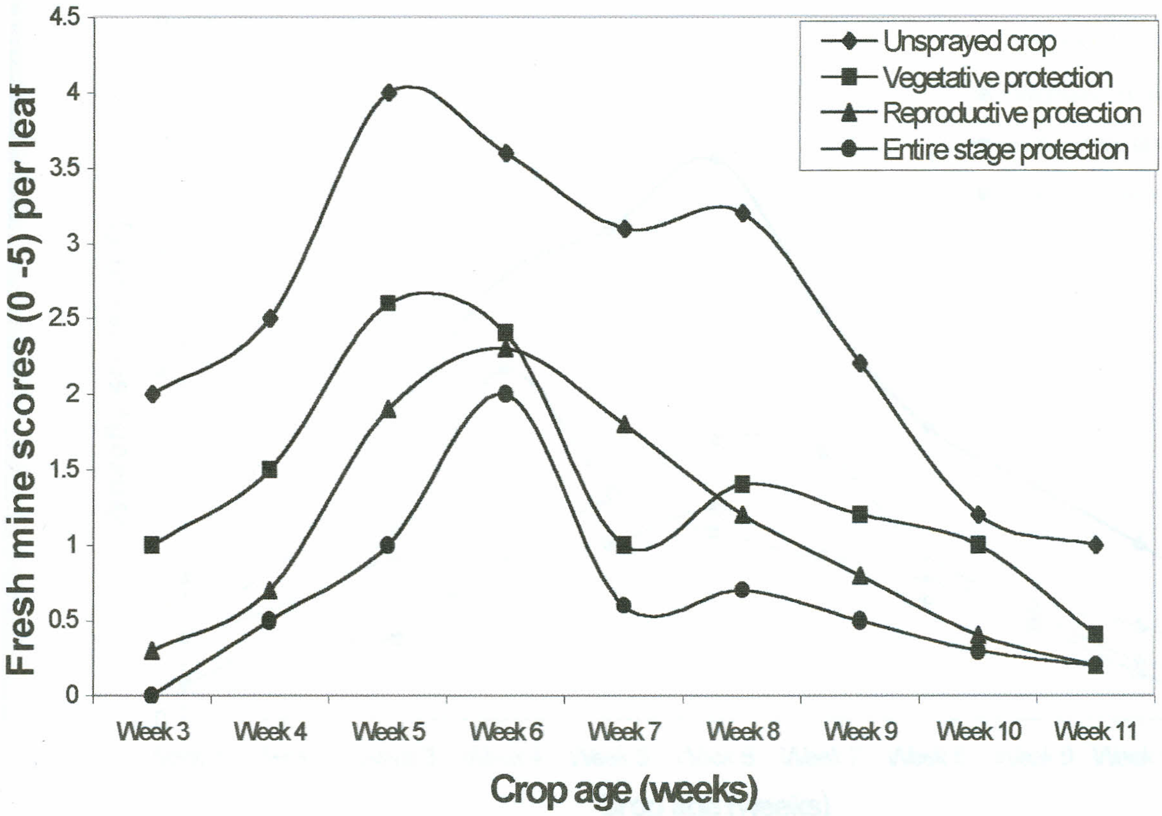


Fig. 4: Relative abundance of whiteflies on cucumber under different chemical protection regimes

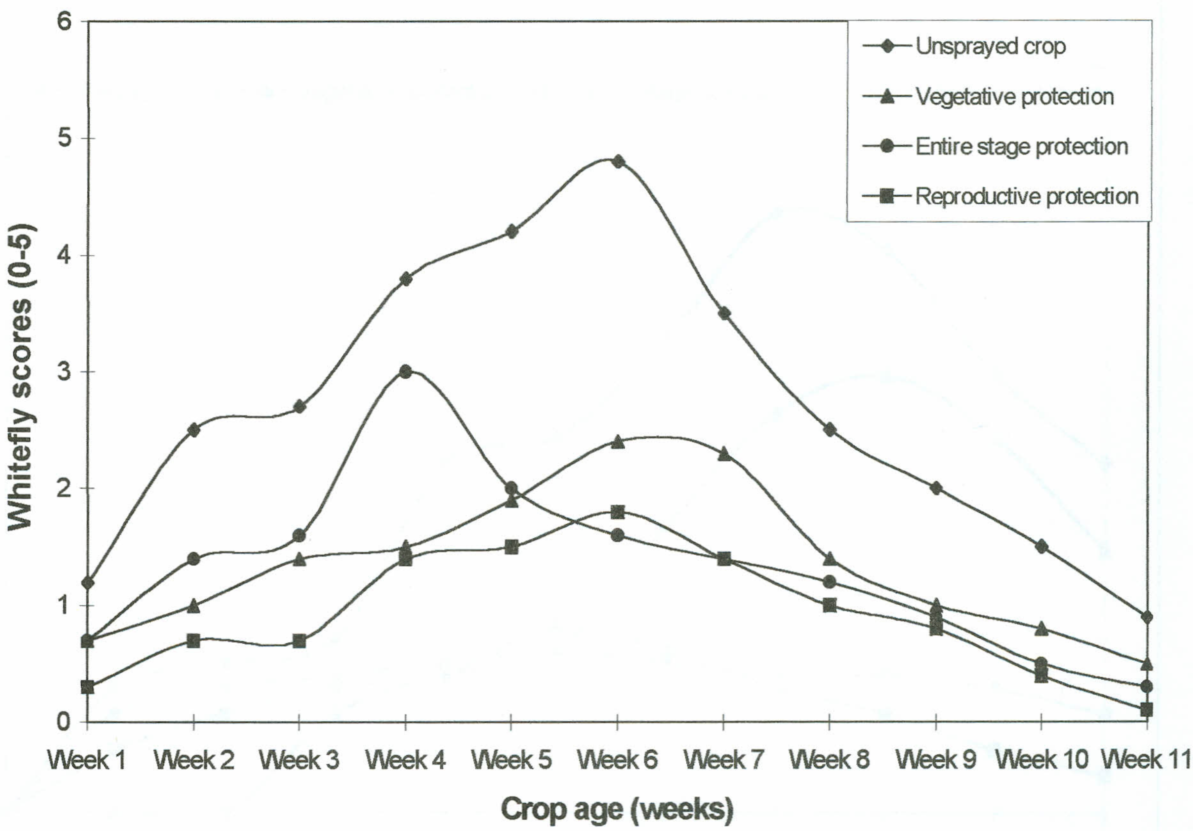
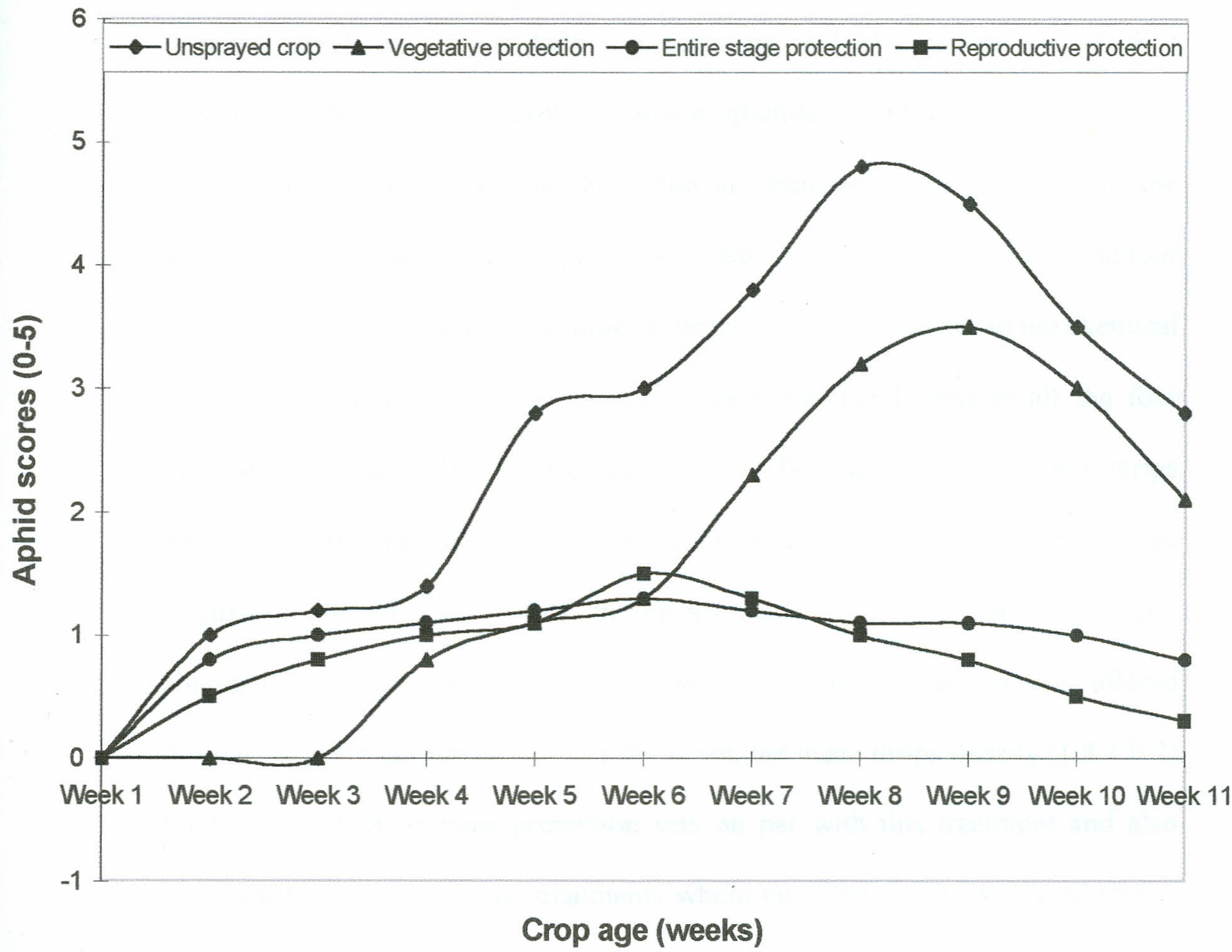


Fig. 5: Relative abundance of aphids on cucumber under different chemical protection regimes.



The defoliating beetles infested the crop from late vegetative stage (Fig. 6). Thus the regime of protection at vegetative stage did not affect their numbers significantly (P>0.05) when compared with the unprotected plots (Table 3). Nevertheless, significant reduction in beetle infestation was evident for protection during the reproductive stage. At flowering, three thrips species, *Frankliniella schultzei* (Trybom), *Thrips tabaci* (Lindeman), and *Mycteothrip* sp. attacked flowers and leaves. The thrips population abundance infesting flowers at the initial reproductive phase was low with an increase in the intensity in the successive weeks as the plant approached peak flower production in all the four treatments (Fig. 7). The mean number of thrips density per flower in the chemical (karate®) protection at the reproductive stage was the lowest in all the four treatments tested (Table 4). However, in the first season, the overall thrips incidence was low. The non-protected plots had significantly higher thrips population density (2.2 ± 0.4). In the second season, the thrips population abundance was also low in the treatment where the protection was offered throughout the plant life (1.6 ± 0.3). However, the mean thrips density (1.8 ± 0.2) for the reproductive stage protection was on par with this treatment and also significantly less than in the treatments where no protection was offered (5.8 ± 0.4) and that in which protection was made at the vegetative stage (4.4 ± 0.2). As fruits formed, fruit fly (*Dacus ciliatus*) population increased and the weighted means are shown (Table 5). The apparent benefit of reproductive stage protection was observed in significant reduction in percent fruits infested, in both seasons (Table 5). The crop protected at the reproductive stage recorded significantly less intensities of fruit fly population as well as infested fruits, which compared favourably with the crop protected at both the vegetative and reproductive (entire) stage crop protection.

Table 3: Effect of different chemical protection regimes on leaf beetles on cucumber.

TREATMENTS	Mean number of beetles on cucumber leaves per plant	
	Season one (Mean ± S.E.)	Season two (Mean ± S.E.)
Non sprayed cucumber crop	18 ± 1.8 a	15 ± 2.0 a
Vegetative stage protection	15 ± 1.1 a	13 ± 4.7 a
Reproductive stage protection	11± 5.1 b	8 ± 3.4 b
Entire stage protection	6 ± 1.6 c	4 ± 2.7 c
Coefficient of variation (%)	31.8	24.9

Means followed by same letter within columns are not significantly different from each other (P=0.05), SNK test.

Table 4: Effect of different chemical treatment protection regimes on flower thrips on cucumber.

TREATMENTS	Mean number of thrips per cucumber flower	
	Season one (Mean ± S.E.)	**Season two (Mean ± S.E.)**
Non sprayed cucumber crop	2.2 ± 0.4 **a**	5.8 ± 0.4 **a**
Vegetative stage protection	1.2 ± 0.2 **b**	4.4 ± 0.2 **b**
Reproductive stage protection	0.6 ± 0.2 **b**	1.8 ± 0.2 **c**
Entire stage protection	1.0 ± 0.3 **b**	1.6 ± 0.2 **c**
Coefficient of variation (%)	47.9	19.4

Means followed by same letter within columns are not significantly different from each other (P=0.05), SNK test.

Table 5: Efficacy of different chemical protection regimes on fruit flies on cucumber fruits

TREATMENTS	Mean number of fruit flies on ten cucumber damaged fruits per treatment / plot		Percent number of fruits infested with fruit flies per plot	
	Season one (Mean ± S.E.)	Season two (Mean ± S.E.)	Season one (Mean ±S.E.)	Season two (Mean ± S.E.)
Non sprayed cucumber crop	27.8 ± 1.50 a	26.8 ± 1.28 a	48±6.60b	46.6±3.80c
Vegetative stage protection	27.0 ± 0.55 a	26.0 ± 0.71 a	32.8±4.20b	42.0±3.20c
Reproductive stage protection	19.6 ± 0.51 b	20.0 ± 1.14 b	27.2±3.20a	28.6±2.70b
Entire stage protection	16.4 ± 1.29 c	13.6 ± 1.50 c	22.8±5.30a	16.6±1.70a
Coefficient of variation (%)	8.6	13.3	13.5	9.7

Means followed by same letter within columns are not significantly different from each other (P=0.05), SNK test.

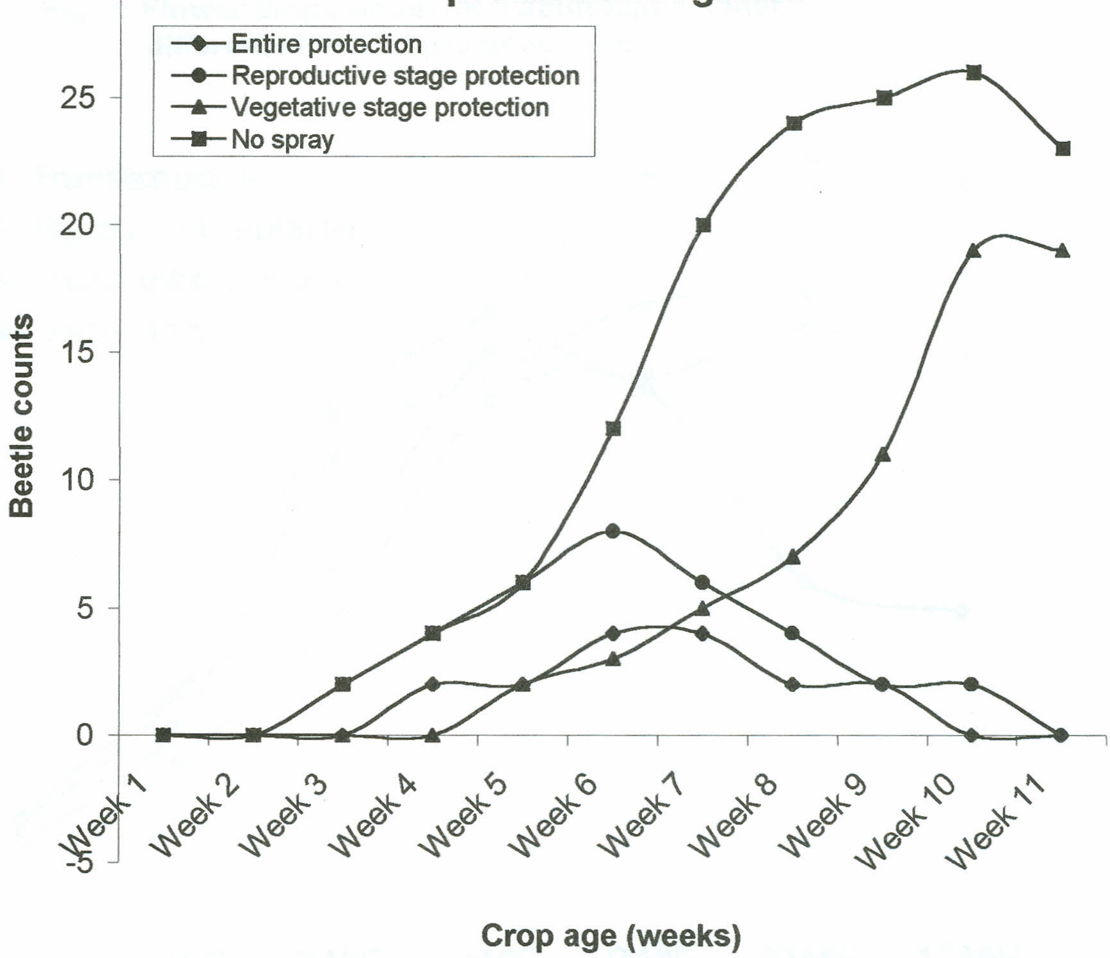
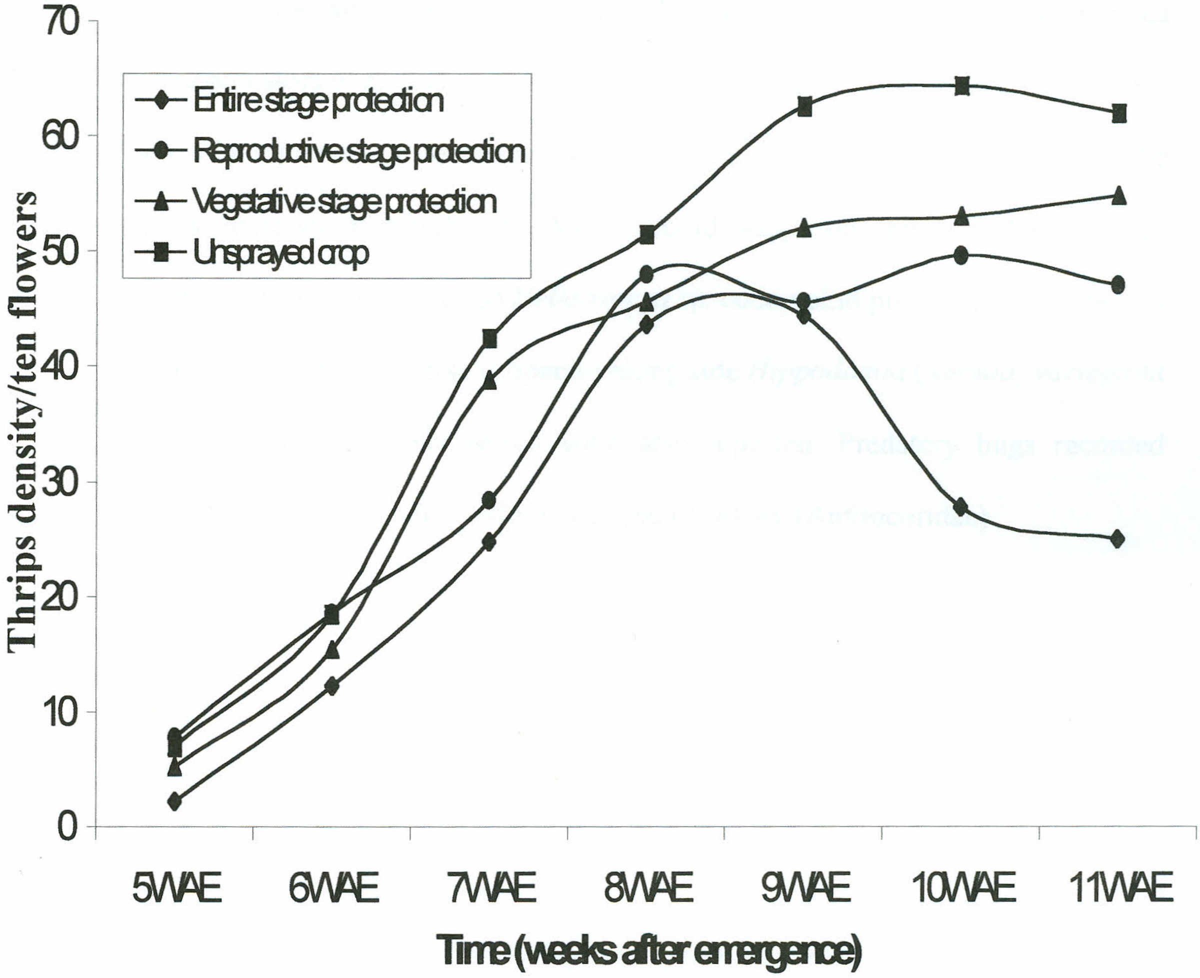


Fig. 6: Relative abundance of leaf defoliating beetles on cucumber under different protection regimes

Fig. 7: Flower thrips population abundance under different chemical protection regimes



3.3. Natural enemies associated with cucumber pests

Several natural enemies were found to be associated with the pests in cucumber agro-ecosystem at the two sites. The natural enemies observed included both predators and parasitoids (Table 6). Majority of the recorded natural enemies were predators of aphids and whiteflies, most of which were coleopterans, besides a few hemipterans. A limited number of parasitoids were also recovered from the pests, majority of which were Ichneumonid wasps on aphids and white flies together with *Charops* sp. on *Helicoverpa* sp. coccinellid predators, *Cheilomenes* spp. were the most diverse in species along side *Hippodamia* (*Adonia*) *variegatta* and *Serangium kunowi* which were also reported. Predatory bugs recorded included *Rhinocoris* sp. (Reduviidae) and *Orius* sp. (Anthocoridae).

Table 6: List of natural enemies (predators and parasitoids) recorded to be associated with cucumber pests at KISE and Kibwezi, in Kenya, 1998 - 2000.

Scientific name	Insect order	Insect family	Pests attacked (Hosts)	
Predators			**KISE**	**Kibwezi**
Cheilomenes sulphurea Olivier	Coleoptera	Coccinellidae	Aphids	Aphids
Cheilomenes lunata F.	Coleoptera	Coccinellidae	Aphids	Aphids
Cheilomenes propinqua Mulsant	Coleoptera	Coccinellidae	Aphids	Aphids
Cheilomenes propinqua propinqua Mulsant	Coleoptera	Coccinellidae	Aphids	Aphids
Adonia (*Hippodamia*) *variegata*	Coleoptera	Coccinellidae	Aphids	Aphids
Serangium kunowi	Coleoptera	Coccinellidae	Aphids	Aphids
Unidentified sp.	Diptera	Syrphidae	Aphids	Aphids
Macroglophus caliginosus	Hemiptera	Nabidae	Whitefly	Whitefly
Orius sp.	Hemiptera	Anthocoriidae	Thrips	Thrips
Rhinocoris sp.	Heteroptera	Reduviidae	Aphids Whiteflies	Aphids Whiteflies
Parasitoids				
Charops sp.	Hymenoptera	Ichneumonidae	Helicoverpa	Helicoverpa
Diaretiella rapae McIntosh	Hymenoptera	Ichneumonidae	Aphids	Aphids
Unidentified sp*.	Hymenoptera	Ichneumonidae	Aphids	Aphids
Pachyneuron sp.	Hymenoptera	Pteromalidae	Aphids	Aphids
Unidentified sp*.	Hymenoptera	Encyrtidae	Aphids	Aphids

sp* - Natural enemy not identified up to generic level

3.4. Field evaluation of neem products

The overall insect infestation in the plots sprayed with the two neem products (oil and powder) is summarised in Table 7. Leaf miners incidence in cotyledonary leaves as well as true leaves was not significantly different (P>0.05) among treatments in the first season. In the second season, leaf miner incidence was significantly less (P<0.05) under neem oil, which had an equal level of control as the plots sprayed with karate. Neem oil recorded significantly less (P<0.05) score for whiteflies than the non - sprayed plots, while neem powder recorded a similar significant (P<0.05) reduction level in one season only. In both seasons, such reduction in neem plots was still not on par with the scores in the karate protected plots. Leaf beetles were significantly less (P<0.05) in the plots receiving neem oil, neem powder or karate than in non – sprayed plots in both seasons. However, the counts in the neem powder spray plots had an equal level of protection as the plots sprayed with karate in both the seasons, while neem oil spray plots were on par only in the second season.

Interestingly, neem powder resulted in thrips counts of an equal level of protection as the plots sprayed with karate in the second season; neem oil recorded significantly less (P<0.05) thrips than non -sprayed plots, but still significantly greater than in the other two treatments. In terms of damage by fruit fly, the intensity per infested fruit in the plots sprayed with neem oil or powder was significantly less (P<0.05) than in non sprayed plots. However the intensity in the neem treatments was significantly greater (P>0.05) than in karate sprayed plots.

The leaf miners were relatively more abundant on neem powder treated than neem oil protected plots both at the cotyledonary (Fig. 8) and true leaf stage (Fig. 9) with the unsprayed plots recording most and the insecticide treated plots having the least infestation. The situation was similar for white flies which were also observed throughout the plant growth stage (Fig. 10). Leaf beetles did not infest early in the plant life but only appeared from the fourth week with the populations building steadily to the tenth week and later tapered off from the eleventh (Fig. 11).

Table 7: Pest scores/counts on cucumber crop in neem efficacy trials (2 seasons)

Pest infestation	Season	Non sprayed (Mean ± SE)	Neem oil (Mean±SE)	Neem powder (Mean±SE)	Karate (Mean±SE)	C.V. (%)
Cotyledonary leaf miners	S_1	4.8± 0.2a	3.2 ± 0.5a	4.8± 0.2a	1.6± 0.4a	37.2
	S_2	4.6± 0.20a	3.0 ± 0.2b	4.4 ± 0.2a	2.0± 0.4c	19.8
Leaf mine scores on true leaves	S_1	3.6 ± 0.50a	2.2 ± 0.2a	3.1 ± 0.5a	2.0± 0.3a	21.7
	S_2	4.4 ± 0.40a	2.4 ± 0.2b	4.0 ± 0.4a	2.6± 0.2b	19.2
Whitefly scores	S_1	4.6± 0.20a	3.0 ± 0.0b	4.4 ± 0.2a	2.0± 0.4c	19.2
	S_2	4.8 ± 0.20a	3.0± 0.3b	2.8 ± 0.4b	1.4± 0.2c	21.1
Thrips counts per 10 flowers	S_1	82.6±16.50a	51.4± 10.1a	26.4± 8.3a	28.2± 9.3a	56.4
	S_2	129.8±14.5a	82.2± 14.9b	46.0± 6.7c	39.4± 5.1c	17.8
Beetles counts per 5 plants	S_1	108.2±18.8a	61.2± 8.1b	21.6± 5.1c	17.6± 1.6c	31.8
	S_2	105.8± 22.0a	55.0± 4.7b	25.8± 3.4b	16.0±2.7b	42.9
Fruit flies per 10 damaged fruits	S_1	32.4±2.8a	21.4± 1.03b	18.6± 1.03b	14.6±1.08c	10.7
	S_2	29.4±2.3a	21.4± 1.03b	19.2± 1.40b	12.6±0.75c	10.0
Percent number of fruits infested	S_1	71.8±3.93 c	43.2± 3.57 b	34.0±3.86 b	29.6±3.00a	15.1
	S_2	72.0±9.28 b	59.6± 6.04 b	19.2±4.28 a	16.6±4.28a	21.6

Means followed by same letter within rows are not significantly different from each other (P=0.05), SNK test.

Fig 8: Relative abundance of cotyledonary leaf miners on cucumber under the neem products efficacy trial

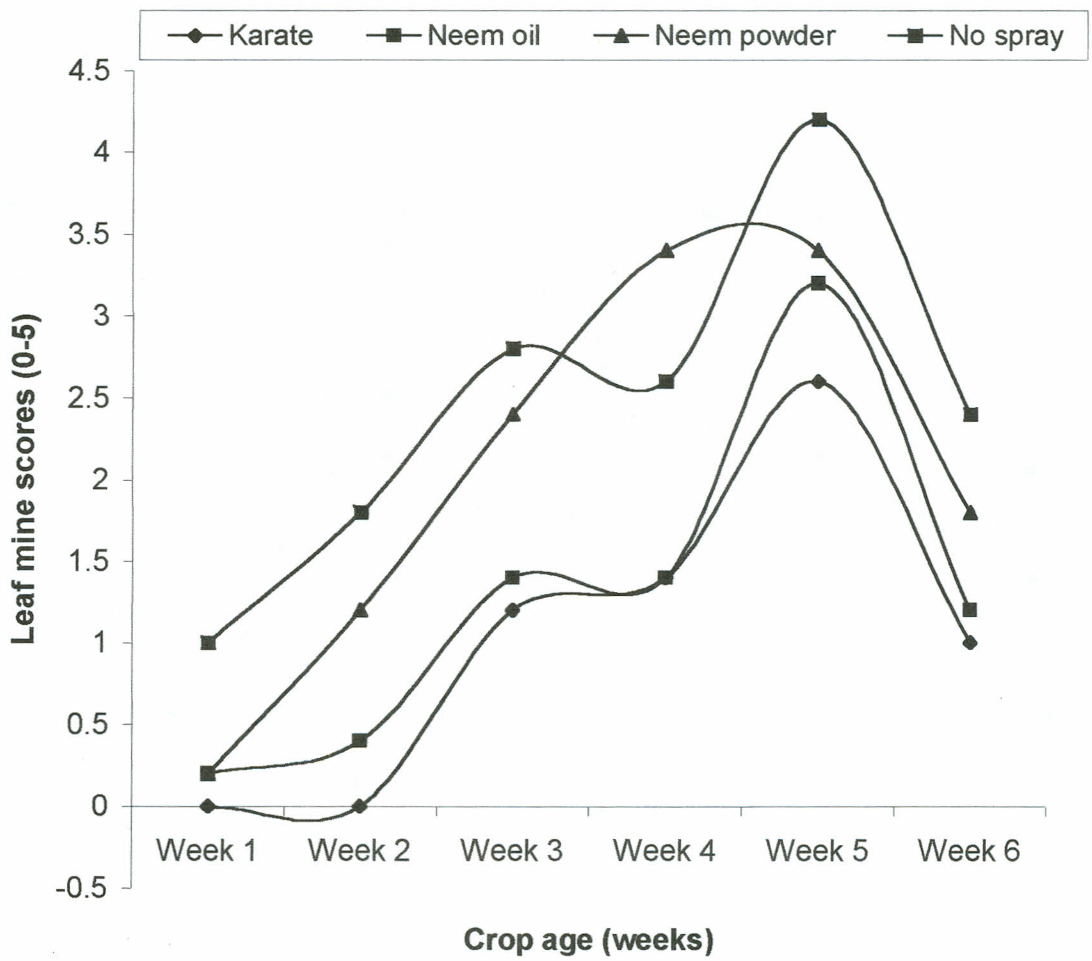


Fig. 9: Relative abundance of leaf miners on cucumber true leaves under the neem products efficacy trial

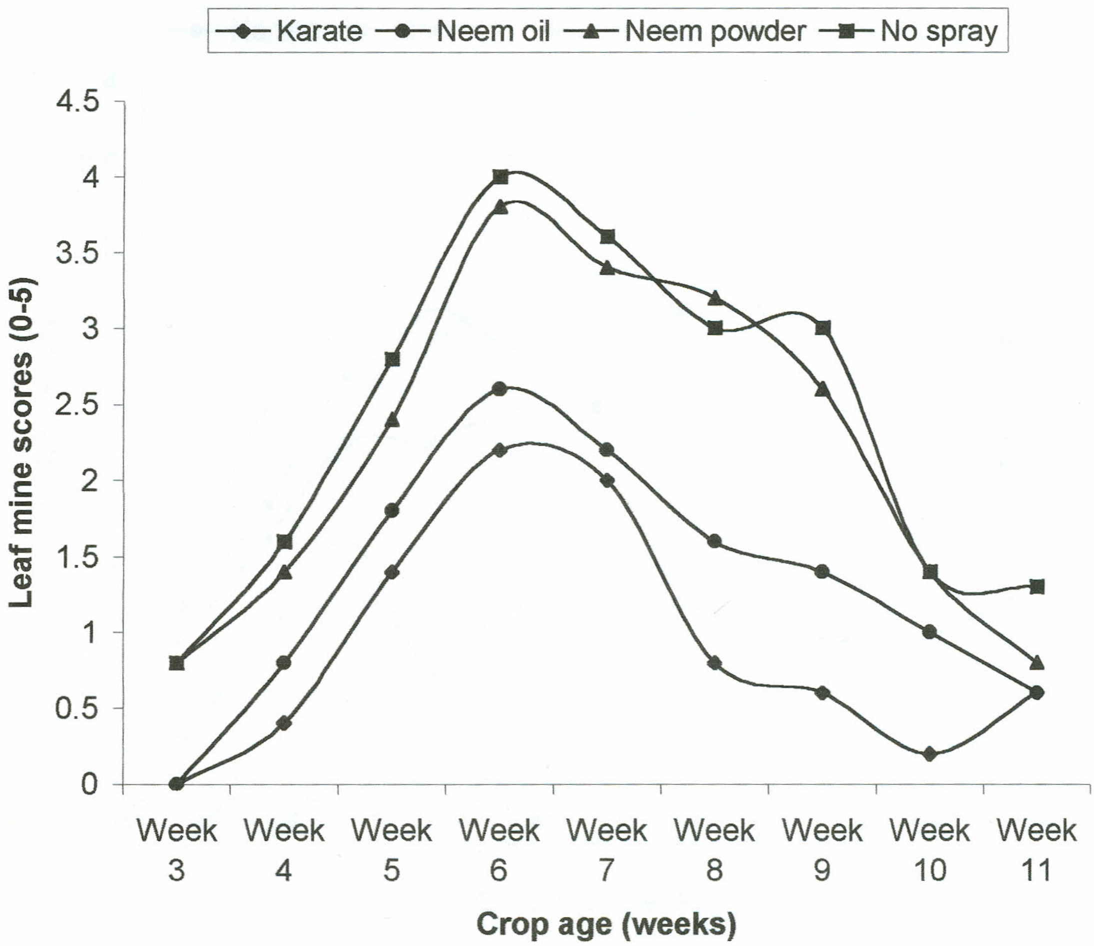


Fig. 10: Relative abundance of white flies on cucumber under the neem products efficacy trial

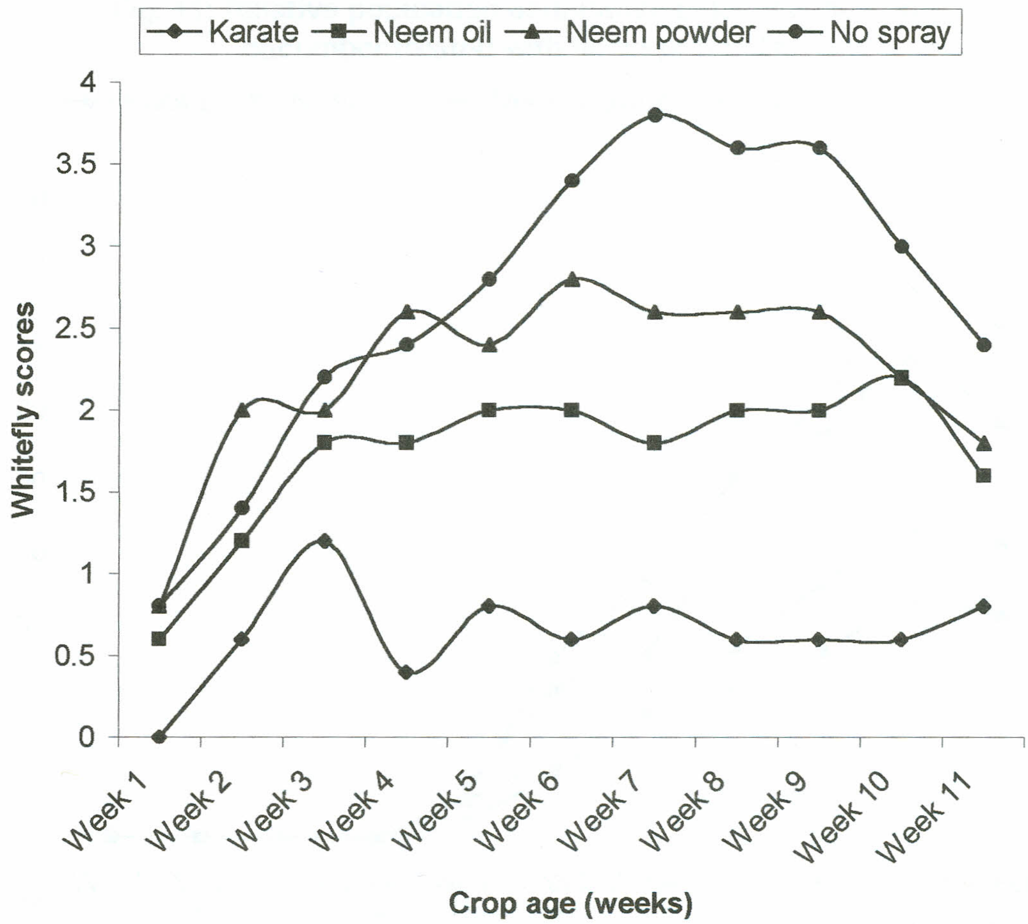
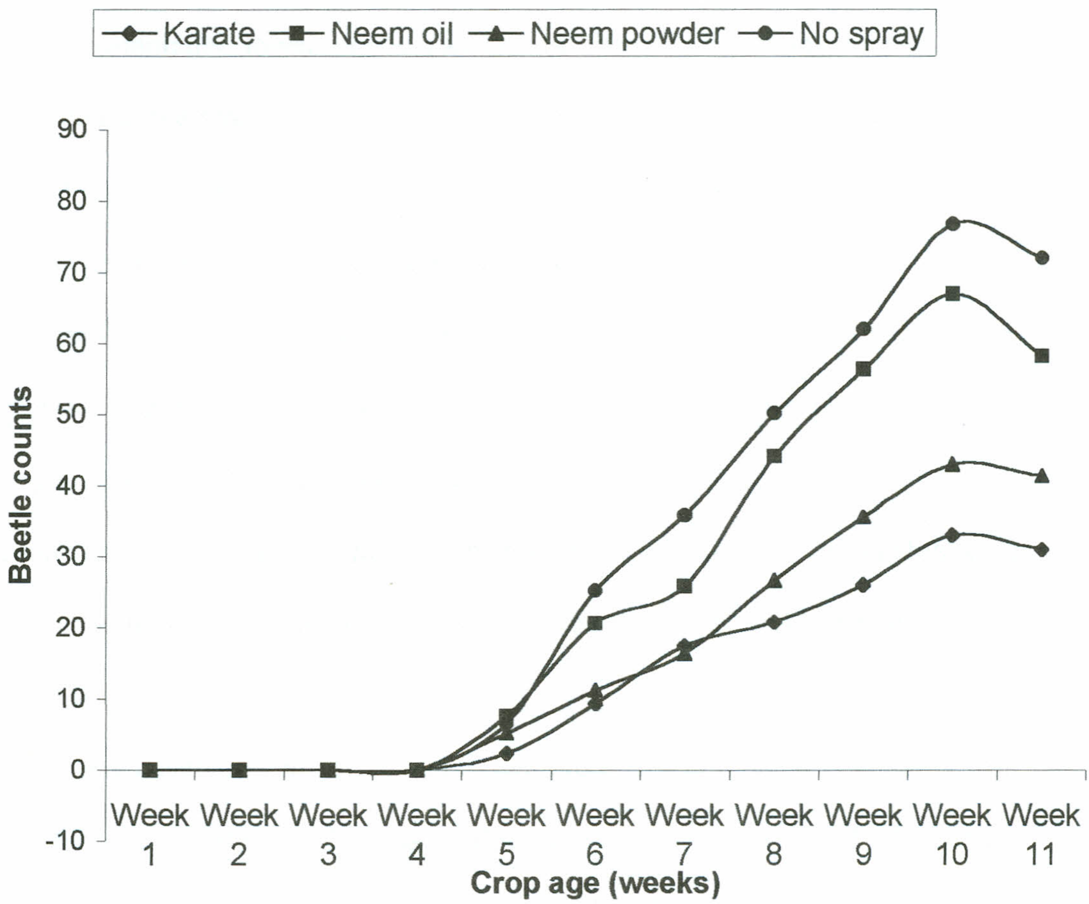


Fig. 11: Relative population abundance of leaf beetles on cucumber treated with neem products



3.5. Cucumber yield and avoidable yield loss under different protection regimes

The unsprayed plots and those with vegetative growth stage protection gave substantially lower yields (weight of fruits) when compared to those protected at the reproductive stage (Table 8). Conversely, crops protected at the reproductive stage and throughout the entire plant life (both vegetative and reproductive stages combined) recorded substantially higher yields. Both the non-protected (unsprayed) crops and vegetative growth protection regime yield data were not significantly different from each other, both in percent number of and weight of damage - free (marketable) fruits. The reproductive stage protection regime and entire plant life protection in both seasons one and two exhibited a considerable reduction in yield losses expressed as percent yield gain of damage-free fruits ($P< 0.01$) (Fig. 12).

Yields attained under neem product protection compared favourably with the chemical insecticide (lambdacyhalothrin/dimethoate) protected plot yields. Neem powder and oil protected plots gave 8.8 and 7.6kg/plot in season one and 9.8 and 6.2kg/plot of damage-free (marketable) fruits in seasons one and two respectively. These were significantly different from Karate/dimethoate and non-protected (unsprayed/control) plot yields of 10.8, 12.8kg and 3.8, 4.0kg respectively for seasons one and two at ($P=0.0001$) and ($P=0.001$) Table 9.

The yield gain due to protection from pests recorded in the neem products efficacy test (Fig. 13) revealed that when no protection was offered, more than 65% and 69% of produced cucumber fruit yields in both season one and two respectively were lost. Protection offered by the neem product oil 30ml/l (aza. 0.03%) had a variable effect. In season one, yield loss resulting after protection was only about 30% where as in season two it was 52%. The neem seed cake powder recorded yield loss of 19% and 23.4% both of which were low when compared to the losses incurred in other treatments. This gave an indication that the neem products apparently conferred a substantial level of protection especially against fruit flies.

Table 8: Seasonal yield of damage – free (marketable) cucumber fruit under the different crop growth stage, Nairobi, 1998 - 1999.

TREATMENTS	**Yield of damage – free (marketable) fruits (Kg/plot)**	
	Season one (Mean ± SE)	**Season two (Mean ± SE)**
Non sprayed cucumber crop	10.4 ± 1.3 **b**	10.7 ± 0.8 **c**
Vegetative stage protection	11.4 ± 0.8 **b**	11.6 ± 0.6 **c**
Reproductive stage protection	14.6 ± 0.6 **a**	14.2 ± 0.5 **b**
Entire stage protection	15.0 ±1.1 **a**	17.1 ± 0.4 **a**
Coefficient of variation (C.V%)	13.4	9.7

Means followed by same letter within columns are not significantly different from each other (P=0.05), SNK test.

Table 9: Percent yield and weight of damage – free (marketable) fruit under the different neem products efficacy test, Nairobi, 1998 - 1999.

TREATMENTS	Yield of damage – free (marketable) fruits (Kg/plot)	
	Season one (Mean ± SE)	Season two (Mean ± SE)
Non sprayed (control)	3.8 ± 0.58 c	4.0 ±1.3 c
Neem Seed Oil (30ml/l, 0.03% aza.) spray	7.6 ± 0.51 b	6.2 ± 0.58 c
Neem Seed Cake Powder (NSCP) 50g/l, 0.5% aza. spray	8.8 ± 0.58 b	9.8 ± 0.57 b
Chemical spray	10.8 ± 0.73 a	12.8 ± 1.02 a
Coefficient of variation (%)	18.4	20.7

Means followed by same letter within columns are not significantly different from each other (P=0.05), SNK test.

Fig. 12: Effect of protection regimes on yield of damage - free (marketable) produce in cucumber, Nairobi, Kenya.

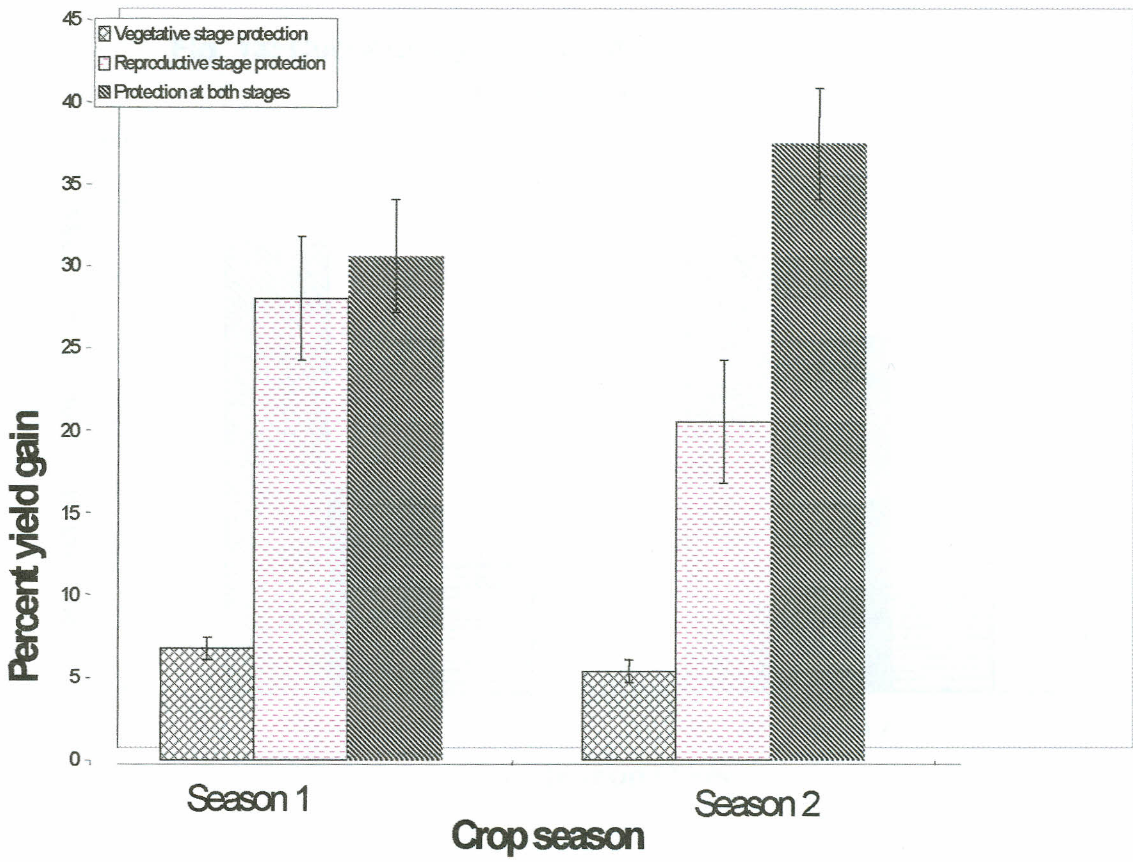
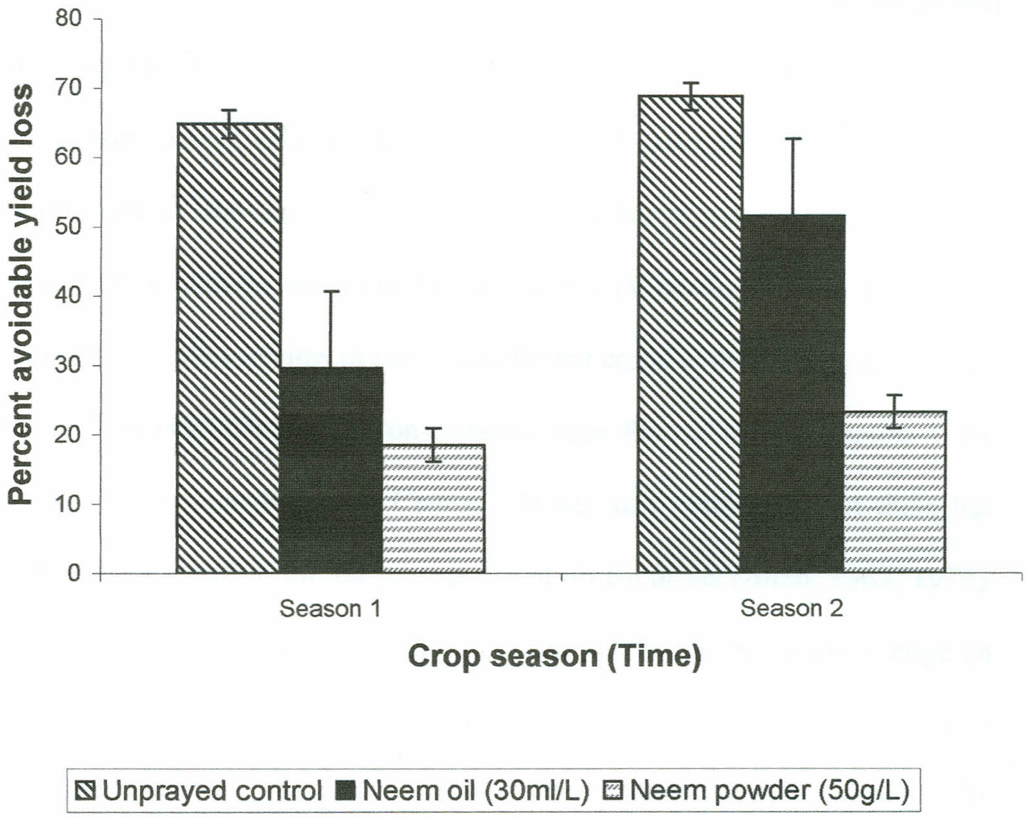


Fig. 13: Cucumber yield gain due to neem products protection



CHAPTER 4:

4.0. DISCUSSION

4.1. Pest spectrum of cucumber

The observations on pest spectrum have resulted in the listing several arthropod pests, the numbers under sucking, chewing and mining pests being ten, ten and three respectively. While these pests are known to occur elsewhere on cucurbits and in the East African region on other crops, most of them are apparently new reports on cucumber for Kenya (Wheatley, 1965). Farrel and Kibata (1998) in their review of pests on different crops in the country have listed only fruit flies as known to occur on cucurbit crops. Perusal through reports of the National Horticultural Research Centre - Thika, also confirmed that there has been scanty information on the pest spectrum on cucurbits (Anon, 1967; 1979). As such, the present results are filling in an important gap in our knowledge on the pest spectrum on cucumber as a model cucurbit crop and thus forms valuable baseline information. During the study, it was observed that the infestation by the major pests of cucumber occurred in succession from vegetative to reproductive stage, which is in conformity with earlier studies reported by Kumar (1984).

The leaf miner infestation on cotyledonary leaves showed peaks at the 4th week for all the treatments at varying score values except for the vegetative stage protection whose peak occurred during the 3rd week at 0.6 which was similar to those of plots protected throughout the entire crop life. Unprotected and reproductive stage protection both attained peak scores of 0.3. Leaf miner infestation among the true leaves experienced two peaks with the first one in the 5^{th} week being the highest for all the treatments and the second one occurred in the 8^{th} week. Unsprayed plots and those with protection (sprayed) limited to the reproductive stage recorded peak infestations greater than the plots receiving protection at the vegetative stage. These findings seem to agree with those of Specer (1973) who reported light infestations early in the plant life in non-protected plots, which gradually became severe with no control measures in the later plant growth stages reaching peak after a period of time and then subsided.

The thrips population density occurring in flowers fluctuated during the crop's reproductive phase; their small size and claustral habits also contribute to the difficulty in investigating directly reasons for the changes in population size within a particular period (Kirk, 1997). In India, population of the tea thrips, *Scirtothrips dorsalis* were observed to decline with the on set of heavy rains compared to warm and dry periods, favouring thrips multiplication (Dev, 1964). Lewis (1973) observed that higher temperatures and absence of precipitation positively influence biotic potential of most thrips species. These conditions need to be researched on to verify if they would yield similar thrips population density fluctuation results in a cucumber crop agro-ecosystem. Post - fertilization retention of dry sepals during fruit development, which is quite evident in Ashley variety, apparently provided the thrips with a sheltered environment, which protected them from exposure, desiccation and rain, a factor that is more important to thrips than food quality (Lewis, 1973). Strong thigmotactic responses compared to light or gravity in many thrips further explain aggregation beneath fruit sepals (Lewis, 1973). The role of climatic factors such as rainfall and natural enemies as possible factors in the population dynamics of cucumber thrips complex should be assessed. The association of thrips complex in cucumber and the identification of the component species are important contributions to our knowledge on their spectrum on this crop in Kenya. This is perhaps also the first time that the thrips complex in cucumber crop has been characterized to some extent in Kenya. However, these pests are generalists which attack a number of cultivated crops like French beans, okra, onion, capsicum and several wild plants which act as reservoirs (alternate hosts) for them when the preferred crop is not available (Odhiambo, 1985).

4.2. Pest attack and abundance in relation to crop phenology

The pests attacking the different parts of the plant varied in their relative abundance during the various crop growth stages but on an increasing trend as the plant grew. Bergonia (1993) recorded similar findings on cucumber in the Philippines. Factors causing variations in population levels of herbivores on plants are not fully elucidated, but a few include impact of predators, inter or intra-specific competition (Kogel *et al.*, 1995; 1996; 1997a). In the present study, such variation in the abundance of herbivores could not be fully studied in relation to both the biotic and abiotic factors. Such studies appear possible for aphids and whiteflies on which several natural enemies were observed. In addition, there is a scope to relate the leaf - infesting insects to their relative positioning on the plant. Leaf positioning suitability is known to influence thrips reproduction, which is usually high on apical leaves and lowest on basal with a peak on the middle ones (Kogel *et al.*, 1997b). In cotton the plant characteristics influence herbivore and natural enemy distribution (Puche and Funderburk, 1995). The influence of spatial association on pest damage and ability of natural enemies to control them has been discussed by Atakam *et al.* (1996). Spatial distribution of thrips may be also used to monitor their density and sex ratios while adult dispersion is known to be a density dependent factor (Atakam *et al.*, 1996).

Aromatic amino acid concentration in cucumber leaf proteins has also been cited to influence thrip colonisation, infestation, growth and development (Mollema and Cole, 1995). Plants possessing higher levels of secondary metabolites such as phenols, ortho-dihydroxy phenols and flavonoids are known to be less preferred. Further studies are suggested on cucumber to link crop physiology and biochemistry with thrips population dynamics. Thrips population dynamics can be monitored using sticky traps (Gillespie and Vernon, 1990; 1995). Visual numerical estimation of densities is also a dependable method since they are highly correlated with absolute densities (Edelson, 1985). Nominal economic thresholds, routine sampling and rapid implementation of controls can help keep thrips populations below economic threshold levels (Jarosik *et al.*, 1995). Some cucurbit stages are known to be resistant to lepidopteran pests such as piclkeworm (Dilbeck *et al.*, 1974). Follow up studies on monitoring the most common pests on cucumber to back up pest control decision making need to be emphasized.

4.3. Range of natural enemies associated and supported in a cucumber agro-ecosystem

The present study has enabled a listing of the locally occurring natural enemies of some of the pests on cucumber. This baseline information can be useful in identifying potential natural enemies to be considered as biological control agents. Among the more common natural enemies found were coccinellid predators (*Cheilomenes* spp.) on aphids and numerous parasitoids (ichneumonids) of both aphids and whiteflies. Further research to find out the potential impact of these natural enemies in the field should be undertaken. Effective and timely regulation of aphid populations by coccinellid predators may normally be achieved in nature under field conditions at low pest population densities (Murdoch, 1972). This may not be feasible at high pest population densities since most of these predators are generalists. Newly hatched coccinellid larvae may remain on their egg batches and even consume unhatched eggs before dispersing (Dixon, 1959) and such cannibalism apparently increase the survival potential of the predator. Aphid - host plant (cucumber) relationship determines the span of time within which coccinellid predators can be effective (Witham, 1978). Searching behavior, voracity and prey density influence the degree of effectiveness in aphid population regulation (Frazer *et al.*, 1981). While preying on aphids, coccinellids may also consume parasitized and mummified aphids as well (Wheeler *et al.*, 1968). This phenomenon may limit the establishment and the rate of increase of parasitoids and their potential for aphid population regulation. Coccinellids are able to exploit aphid populations optimally with respect to their own population dynamics. They may not be able to suppress and keep the aphid numbers low enough or do for a very long time without adoption of other control measures (Barlow and Dixon, 1980).

Elsewhere in diverse crop agro-ecosystems, predatory coccinellids and surphids have presented themselves as successful biological control agents. This is due to the positive response to prey availability possibly as a result of the resource concentration principle (Frazer, 1988). In Nigeria, Ofuya (1986; 1990) showed the voracity *Cheilomenes* sp. on different stages of aphids and the ability of adult predators to suppress aphid populations in both laboratory and field experiments. Ofuya (1986) suggested that the inefficiency of some aphidophagous ladybirds as biological control agents was a consequence of their poor ability to exploit unstable food resources. There are records of aphid population explosion following the use of chemical insecticides (Don-Pedro, 1990; Ofuya, 1987) presumably because these chemicals eliminated the natural enemies such as coccinellids and surphids. The study emphasizes on rational use of insecticides so as to promote conservation of predators and parasitoids in cucurbit agro-ecosystem. This may enhance their population that may eventually play a role in pest population regulation, though this may not give a great impact since most of the predators are generalists with poor searching abilities (Ofuya, 1987). Since neem products are known to be less toxic to natural enemies, they may be used to suppress major pest populations with synthetic chemical applications only when pest population outbreaks occur (Heyde *et al.,* 1984; Saxena, 1989; Saxena *et al.,* 1989).

The complexes of defoliating beetles observed in cucumber in the present study areas were not attacked by any of the natural enemy groups. Nevertheless, it would be useful to pursue such surveys in additional sites and seasons to see if any native species are available for use as biocontrol agents of this group of pests. Biological control measures have often been used independently or in combination with other methods to reduce the infestations of the spotted cucumber beetle, *Diabrotica undecimpunctata* (Mann) (Lorenzate, 1984; Barbercheck, 1995). Biological control agents such as *Celatoria diabroticae*, are effective in suppressing spotted cucumber beetle populations (Barbercheck, 1995). Additional natural enemies recorded to suppress spotted beetle on cucumber in Germany include *Celatoria setosa* and a braconid, *Syrrhizus diabroticae* (Barbercheck, 1995). Nematode species *Neoaplectana carpocapsae* and *Heterorhabditis* have been conveniently applied through trickle irrigation (Reed *et al.*, 1986). The African melon ladybird, *Epilachna chrysomelina* F., population is recorded to be regulated by a predatory rheduviid bug (*Rhynocoris fuscipes*) and soil microbes such as *Aspergillus flavus* and *Bacillus thuringiensis* elsewhere (Rajagopal, 1989). However, evaluation of the potential of *Bacillus thuringiensis* strains available commercially as biocontrol products of lepidopteran pests on cucurbits needs to be validated.

Aphids on cucumber were also found to be attacked by a number of natural enemies especially parasitoids. The aphid and whitefly populations are known to escalate when their natural enemies are inadvertently killed through pesticide application. They are also reported to have developed resistance to chemical pesticides such aspirimor (pirimicarb), vertimec (Abamectin) except lannate (methomyl) (Albert and Merz, 1995). Natural preparations such as Neudosan (potassium soap) and Telmion (rape oil) can be applied before or with beneficial insects (Albert and Merz, 1995). A parasitoid, *Aphidius colemani* (Hymenoptera; Aphididae) (Viereck) has been used to control *Aphis gossypii* (Homoptera: Aphididae) (Glover) in green house grown cucumbers in Netherlands (Steenis, 1996). *Lysiphlebus testaceipes* (Hymenoptera: Braconidae) (Cresson), parasitoid, was used in Ukraine and achieved 83-100% aphid control within 20 days. Abundance of melon aphids has been reduced under a combined action of aphidophages and entomophatogenic fungi in USSR (Pavlyushin, 1987). *Trioxus indicus* has also produced similar positive results in India (Bhatt, 1989). Predatory midges and *Aphidoletes aphidimyza* (Diptera: Cecidomyiidae) (Rondani) gave promising results in greenhouse cucumbers in the Czech republic

(Guenaoui, 1991) and the predatory hemipteran, *Deraocoris punctulatus* was shown to be able to consume about 1248 aphids in its entire life-span (Kimsanbaev, 1991). This expresses the potential of the hemipteran in controlling aphids and hence presents it as a promising candidate for aphid biocontrol.

Whitefly population regulating agents such as *Paecilomyces fumosoroseus* Apopka 97, a strain of entomopathogenic fungi is excellent in controlling *T. vaporariorum* (Fang *et al.*, 1986). Entomophagous fungi of *Aegerita* sp. and *Aschersonia* sp. also have a potential when used together with natural enemies like *Encarsia Formosa* (Hymenoptera: Aphelinidae), *E. californicus* like *Delphastus pisillus, Macrolophus caliginosus,* predatory bug and pathogenic fungi such as *Aschersonia* sp., *Verticillium lecanii* and *Paecilomyces* sp. (Fransen, 1994; Lenteren, 1995; Sovia *et al.*, 1996). *Eretmocerus mundus* (Hymenoptera: Aphelinidae), a parasitoid is recorded to have reduced *B. tabaci* pupae population by 11% (Ginko, 1996). In Texas, USA *Chrysoperla rufilabris* has been found to have predated on whitefly larvae in water - melon greenhouse and brought down their populations (Legaspi *et al.*, 1996). *Encarsia pergandiella* (Hymenoptera: Aphelinidae) is also a promising agent (Goolsby, 1996). *Deraeocoris punctulatus,* a predatory hemipteran was used to reduce the number of sucking pests on cucumber since it feeds on the larvae and eggs of the whitefly (Kimsanbaev, 1991). The use of cultural practices such as transparent plastic mulch that has proved effective in reducing whitefly populations in Russia can complement biocontrol agents (Abbass, 1998). In USSR, 85% - 90% or even 100% control of whitefly (*Bemisia tabaci*) has been achieved on cucumber in greenhouses with the help of transparent plastic mulch material (Cherkasov, 1986).

The study conducted at the two sites were not so successful in locating natural enemies on the fruit flies in cucumber. Nevertheless, studies on other fruit flies such as *Ceratitis* spp. under the African fruit flies initiative based at ICIPE in conjunction with the National Museums of Kenya has shown the natural occurrence of a number of native parasitoids on several fruit crops in the region (De Meyer, 1996; 1998). Revision of the subgenus *Ceratitis* (*Ceratalaspis*) Hancock (Diptera: Tephritidae) by De Meyer (1998) has revealed that this genus comprises several important pest species attacking a wide range of unrelated fruits thus supporting a complex of parasitoids. Tephritids usually attack cucumber fruits thus cause yield loss, and the adoption of simple control measures such as use of paper bags and burrowing of fruits in the soil reduce losses incurred due to their infestation (Fang and Chang, 1987). Strategies to conserve and utilize natural enemies as the main control tactic would be preferred since they are cost effective and readily available. In Kenya, Stoetzer and Kinyagia (1980) recorded melon fly, *Dacus cucurbitae* (Coq.) to be a serious pest that causes rotting of fruits (Le Pelley, 1959). Kibata (1990) noted three parasitoids attacking it and they include *Dirhinus* sp. (Chalcididae), *Spalarigia afra* (Pteromalidae) and *Tetrastichus giffardii* (Eulophidae).

Despite the common availability of leaf miners, the limited samples of the mines did not lead to recovery of any natural enemies. Perhaps the periodicity and the intensity of sampling should be enhanced to ascertain if any useful parasitoids occur locally. Elsewhere, leaf miners have been recorded to be suppressed by hymenopteran parasitoids such as *Hemitarsenus varicornis* (Girault) (Eulophidae) and *Gotoma* (Eucoilid). In India, *Chrysonotomyia* sp. is reported to parasitize maggots of the fly (Shanker *et al.*, 1992). Parasitic wasps like *Solenotus intermedius*, *Diglyphus* sp. and *Chrysocharis* sp. have been observed to regulate leaf miner populations on cucumber in California (Godfrey *et al.*, 1997). Other parasites such as *Ganaspidium hunteri* (Crawford), *Chrysocharis parksi* (Hymenoptera: Eulophidae) Crawford, *Cothonapsis pacifica* Yoshimoto and *Haliticoptera circulus* (Walker) and *Opius dissitus* (Hymenoptera: Braconidae) (Muesebeck) have been recorded in Hawaii (Lynch, 1986; Johnson, 1987).

The lepidopteran pests observed in the present study were not adequately sampled for parasitism or pathogens due to poor infestation, however, a more concerted effort would be required to realise this goal when their natural populations bloom. Surveys conducted by ICIPE have recovered some egg parasitoid species and have also assembled baculoviruses, nuclear polyhedrosis virus (NPV) occurring on *H. armigera* in Kenya; a pest that has been found to attack cucumbers as well. The recovery of *Charops* sp. from it provides hope of recording other natural enemies in the region in a more intensive study. Generally, the fruit borer is recorded to be parasitzed by *Trichogramma confusum* (*T. chlonis*), *Schenocharops* sp., *Apanteles* sp. and *Elasmus* sp. (Ke *et al.*, 1988). *Apanteles taragamae* (Hymenoptera: Braconidae) have also been recorded (Peter and David, 1992). Plants carrying glabrous mutation are reported to be resistant to pickleworm, (*D. nitidalis* Stoll) and enable parasitic wasp *E. formosa* to parasitize *T. vaporariorum* more readily (Ke *et al.*, 1988).

There is need to establish a strong research base in locating native natural enemies of thrips infesting cucumber flowers. Recent studies by Gathu (2000) and Gitonga (1999) have shown the common occurrence of predators *Orius* sp. and parasitoids like *Ceranisus menes* on thrips on French bean in Kenya. These are possible indications that this pest is common among the cultivated crops and wild plants thus making it a constraint to vegetable production. Thrips control effectiveness is site, season, crop variety influenced (Hansen, 1989). *Orius* sp. (Hemiptera; Anthocoridae) are known to regulate their population (Hill, 1983; 1988). *Amblyseius cucumeris* N. (*Neoseiulus cucumeris*) and *A. limonicus* are predatory phytoseiid mites known (Hill, 1988). *Amblyseius barkeri* (Hughes) (Acarina; Phytoseiidae) successfully controlled *T. tabaci* in Denmark (Jarosik *et al.*, 1995). Goven and Ozgur (1990) in Turkey recorded twelve different predators, of which *Orius* sp. and *Adonia variegata* (*Hippodamia variegata*).

4.4. Field evaluation of neem products

The field trials have shown the extent of pest control benefits that could be derived from using the two neem products; although they were not as effective as the chemical pesticide check (Karate®) against the common pests observed. This is understandable since the modes of action of neem are more subtle compared to the quick mortality caused by the contact toxicants. In neem literature, such trend of intermediate efficacy of neem products compared with chemical pesticides is very common. Neem products have been shown to be active against 198 different species of insect pests (beetles inclusive) while they apparently do not kill or only show weak adverse effects on many of the beneficial insects such as pollinators, predators and parasitoids (Saxena, 1989; Saxena, *et al.*, 1989; Schmutterer, 1988; 1990; 1995). The present results are in agreement with those from India. Different Chemical insecticides like pyrethroids, cypermethrins, malathion and endosulfan were superior to the neem products in the country on *Helicoverpa armigera* (Hübner) defoliating bean leaves (Parmar and Srivastava, 1987). Atiri *et al.* (1991) comparing natural and synthetic chemicals on the incidence, severity and total damage by beetles on okra however, found that lambdacyhalothrin, (synthetic pyrethroid) and aqueous neem solution are both easily degraded by the metabolizing systems of phytophagous beetles. The adverse effects of metabolized neem products are usually expressed as malformations in their progeny. Since neem products are likely to be less expensive than synthetic chemicals in areas where neem seeds are readily available and the preparation of the extract is cheap and hence may be preferred for use as pest control products, farmers in such regions may find using it quite cheap. Neem products and *Cedrela ordata* (Spanish cedar) extracts have been recorded to deter striped cucumber beetle (*Acalyma vittatum*) from feeding on sprayed cucumber leaves (Jacobson, 1989).

Between the two neem products – neem powder and neem oil – there have been differences observed in their relative efficacy on cucumber pests. Neem oil has shown promise against leaf miners and whiteflies while neem powder was more effective on thrips; both were however equal in controlling the infestation by the fruit flies. Srivastava *et al.* (1986) reported that application of neem seed oil at 0.5%: water emulsion inhibit cucumber mosaic virus (CMV) through topical application while the same product did not affect biological activity of viruses as evidenced through a mechanical transmission test (MTT) (Serra and Schmutterer, 1993). Use of neem products has been found to benefit by both direct control of *M. persicae* and reduction or delay in spread of the non persistent plant viruses (NPPV) (Lowery *et al.*, 1997). Both field and laboratory trials with formulated neem seed oil (NSO) and neem seed kernel extract (NSKE) have been found to show strong aphicidal effects on *M. persicae*. NSO has been reported to reduce aphid numbers in a dose - dependent manner with an estimated EC_{50} ranging from 0.2 to 1.4%. The effectiveness of the neem products in some trials appeared to be influenced by host plant, aphid species and weather conditions (Lowery *et al.*, 1997). Mishra *et al.* (1989) found that feeding 0.05% NSO to epilachna beetle, *Henosepilachna* [*Epilachna*] *sparsa* (Hbst.) increased the duration of life stages in subsequent generations and reduced weights. Females of the beetle when fed on 0.05% NSO treated leaves showed longer preoviposition and shorter oviposition periods with long term effects on fecundity (Mishra *et al.*, 1989). Jeyarajan and Babu (1990) reported anti-feedant activity of NSKE at 1000 ppm to the 4^{th} instar larvae and adult of the epilachnine beetle (*Epilachna sparsa* Hbst.). *E. dodecastigma* (weid.) larvae and adults exposed to leaf discs treated with NSO of concentrations ranging from 0.25 to 2.0% showed decreased feeding activity with increasing oil concentrations (Haque *et al.*, 1996). The present studies on field evaluation of neem products and recording of the naturally occurring pest infestations should be complemented by studies on their concurrent effects on the natural enemies, so that a more holistic assessment of the ecosystem benefits of the use of the neem products could be made. It would be also useful to undertake trials to optimise the dose rates of the promising neem products in order to derive the best impact possible.

Experiments to test the efficacy of the neem products gave results, which exemplified that there was a general improvement in the yield of damage free harvested fruits (weight) under neem treatments in both seasons (Table 8). In season one, the yield of damage-free (marketable) fruits in the unsprayed plots (3.8 kg) was half that recorded under the neem seed oil protected plots (7.6 kg) and the two were also significantly different from one another at (P=0.001). The yield obtained under neem seed oil protection was not statistically different from that attained in the neem powder protected plots though there was a slight improvement in the attained yield. Standard check (chemical insecticides protected plots) recorded a substantial amount of yield 10.8 kg though this was only a small improvement over the neem - protected plots.

4.5. Effects of protection regimes on yield losses

Based on the results on cucumber in the present study, it was found that avoidable loss due to pests occurring in the reproductive crop growth stage was clearly more significant than in the vegetative stage. This clarified that it would be more economical to invest in a protection regime that covers the reproductive stage of cucumber growth. Protection during this stage yielded almost similar to the levels as when the crop was protected throughout growth stage. Assessment of the overall effect of insect pests on the yield and quality of produce need to be further determined, as the study did not partition individual insect caused yield losses. The results showed that the yield of marketable (damage – free) fruits was enhanced significantly in both the seasons when the crop was protected from pests during the reproductive stage but no significant increase occurred when protection was given during the vegetative stage. Even though protection throughout the entire plant life gave the highest yield, was not significantly greater than the plots protected at the reproductive stage despite the early starting of chemical sprays. This information provided a basis to focus further research on pests occurring in the reproductive stage of the cucumber crop.

Dent (1994) included growers' attitude and level of awareness, the cropping system, weather, the level and type of input and also the severity and incidence of pests and diseases as factors that govern crop yields. Farmers often opt for yields that give highest possible return on input investment 'economic yield' (Dent, 1994). Since the presence of different insect pests on the crop could cause different levels of damage, the present study could be broadly extended to estimate losses caused by individual groups of pests such as sucking pests, defoliators and borers/miners on cucurbits. The type of pest damage is known to influence both the probability and extent of yield loss. Some plants can tolerate certain amounts of defoliation without any effect on yield through compensation by enhanced growth (Glass, 1975; Kumar, 1984). Planting of such pest tolerant/resistant cucumber cultivars may further refine the crop protection strategy and improve the attainable yield (Kumar, 1984).

Stern (1973) suggested that lack of knowledge on yield/pest density ratio that has unquestionably led to frequent erroneous judgments and unnecessary control measures. A number of measures have been taken to ensure increased pest damage - free (marketable) cucumber fruits. The present results have shown that in cucumber, reproductive stage pests such as thrips and fruit flies appear to cause substantial yield losses; therefore gain in marketable yield due to protection is plausible when targeted on pests attacking at this stage. This is indeed useful information for pest control decision-making. Besides these methods, the following possibilities have also been explored elsewhere and may be considered where appropriate for pest control on different vegetable crops. The use of predatory cecidomyiid (*Aphidoletes aphidimyza*) and *Cycloneda* sp. to control green peach aphids (*M. persicae*) resulted in yield increases of 0.3 kg/m^2 and melon aphid control gave 0.2 kg/m^2 yield increases on cucumber (Begunov and Storozhokov, 1986).

Among the pests observed to infest cucumber during the vegetative stage, aphids and whiteflies also contribute a substantial proportion of loss through vector attack besides direct yield losses. Whitefly population suppression through the use of biological agents on cucumber is known to have increased yields by 17% and 14% in the variants involving mass reared *Encarsia* sp. and mass cultured *Verticillium* sp., respectively, and production costs were reduced by 16% and 13% in the same order (Cherkasov, 1986).

Chewing insects that defoliate leaves cause foliar damage as the insects feed and thus reduce market quality and quantity of harvestable products directly or indirectly (Southwood and Norton, 1973). Plants can tolerate certain amounts of defoliation without any effect on yield through compensation of damaged tissue by enhanced growth (Poston *et al.*, 1983). Damage caused by pathogens (bacteria or viruses) transmitted by such vectors *as D. undecimpunctata, A. gossypii, B. tabaci* influence both probability and extent of yield loss to a crop (Hill, 1983). The sequence of proportionate distribution of photosynthetic material to particular organs during development physiologically, facilitates understanding of the relationship between timing, intensity of pest attack and crop yield (Evans, 1972).

The substantial yield benefit observed in the present study for protection during reproductive stage in cucumber could be attributed to control of the fruit fly infestation. The sampling of harvested fruits in different plots has shown that fruit damage by fruit fly is a major cause for concern, as it affects the marketable yields. When fruit flies attack cucumber (Nakamori and Shiga, 1993) or bitter gourd (Fang and Chang, 1987) fruits, substantial loss in yield is often experienced. They reduce fruit market value and render them unfit for consumption (Nakamori and Shiga, 1993). In the field, fruit fly population increase from initial flowering stage and reaches peak when fruit number is highest and later on declines but, this varies with seasons (Wong *et al.*, 1989; Chen *et al.*, 1995). Environmental and climatic factors besides type and stage of crop have a great bearing on fruit fly populations (Wong *et al.*, 1989). While the present yield studies have provided the basis to assign greater importance generally to the pests affecting cucumber at the reproductive stage, further insight would be worthwhile to point out specifically the exact time of the reproductive stage when it may merit selective protection from the pests. Such a study will also lead to need – based pest control, thus minimising control costs as well as the extent of pesticide used on the crop.

CHAPTER 5:

5.0. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

It is clear from the present study that the cucumber crop encounters infestation by arthropod pests that cause substantial yield losses in terms of quantity and / or quality of fruits finally harvested. The study ascertained the important crop growth stage (reproductive) that gave better returns for investment in pest control. The study found associated with some of the pests, several native natural enemies that could be candidates for testing as biocontrol agents against the pests.

It is apparent from the present study that protection at the reproductive growth stage would be economically justifiable. This is an important baseline information that could help refine the pest control strategy leading to a reduction in chemical insecticide use, thus minimize pesticide residue levels (load) (low MRLs) on the produce. It would also in effect help cut on the pest control costs/expenditure. Protection of the crop at the vegetative stage, even though it gave minimal / low pest population infestation, it did not improve much on the damage - free harvestable yields as compared to protection offered at the reproductive stage. Protection of cucumber at the vegetative growth stage was no doubt found to reduce infestation by defoliators and sap – suckers, especially coleopterans and homopterans generally, whose direct contribution to yield loss in surviving plants is quite minimal as shown by the yield results. This is nevertheless true as long as their populations are below economic thresholds, but if their populations rise substantially than the levels observed in the present study, there would be need to critically revisit the rationale. It is known that the crop suffers significant losses in situations where the economic thresholds are reached thus causing yield loss through reduction of plant stand or reduced plant photosynthate availability which reflects in the yield quantity and quality.

The present study has helped in understanding the pest spectrum on the crop across the entire crop growth cycle. The pests that occur during the vegetative and reproductive stages have been identified and their relative severity at the two sites understood.

Further reduction in the stand of healthy plants can also result from virus transmission by aphids and whiteflies, which may eventually contribute to substantial yield loss. Further cosmetic damage to fruits, through honey dew production by aphids /whiteflies may affect the quality of the harvestable fruits in treatment regimes where protection was only at the vegetative stage alone or when not protected at both crop stages. Therefore the findings of the present study on gains due to selective protection from pests occurring at the two crop growth stages should be reinforced with further studies on different severity levels of the key pests and this will help refine our decisions on pest control.

It was evident that both the neem products (oil and powder) may offer scope and alternative control measure to some of the pests infesting cucumber crop at different growth stages. Promising results with neem products comparable to those of Karate® [lamdacyhalothrin] treated plots were obtained in the control of the early infesting pests such as leaf miners attacking from cotyledonary leaf stage. This benefit of neem may further be sought for improvement through seed treatment with neem products such as Neemros® and Neemroc® by selecting the optimum dosages of neem products as well as the timing of their applications.

5.2. RECOMMENDATION

Crop health, proper initial plant stand establishment and natural occurrence of pest populations ensure a great success in any field experimental design. Basing on findings of the present study, it may be recommended that when chemical insecticides are to be used as a means of pest control in a cucumber when all other crop influencing factors such as soil moisture, temperature, fertility, seed viability, disease incidences are held constant, the crop protection intervention may be more economical when intensified at its reproductive stage rather than at the vegetative stage. Occasional protection may however, be resorted to at either the early or late vegetative stage if the pest infesting becomes severe so that the crop is not totally lost through disease pathogen transmission. Neem products often give a promise for use preferably in combination with other safer control agents such as *B.t.*, mass reared natural enemies to enable sustainable management of key pests such as whiteflies and fruit flies. Different dosages of the neem products should be tested to enable recommendation of optimum dosage and appropriate frequency for controlling the individual key insect pests. Additional tests with other commercially available neem products such as Achook® should be included in future trials and their efficacy verified on the key individual insects.

To gain a more generalised understanding of the pest spectrum on cucumber in Kenya, it would be important to undertake similar studies in other major cucumber growing parts of the country since the present study involved only two sites which may not be representative enough. Further specific quantitative studies on individual key pest species should be carried out to determine their contribution to yield loss on the crop. Cheaper control options like use of botanicals, paper bags, soil fruit covering that are based on using locally available materials should also be further explored and their potentiality assessed. Since cucurbits are becoming increasingly important crops both for local consumption (urban) and export, pest control methods that rationally employ minimal or no chemical pesticides need to be identified, researched on and promoted in the production of the crop. The knowledge on locally occurring natural enemies should be strengthened for promoting use of bio-control agents and products.

Future investigations to find out safer alternative methods of controlling the pests of cucumber occurring at reproductive growth stage such as fruit flies and thrips should be encouraged. There is need to also investigate the possibility of virus transmission by the thrips, white flies and aphids in cucumber crop.

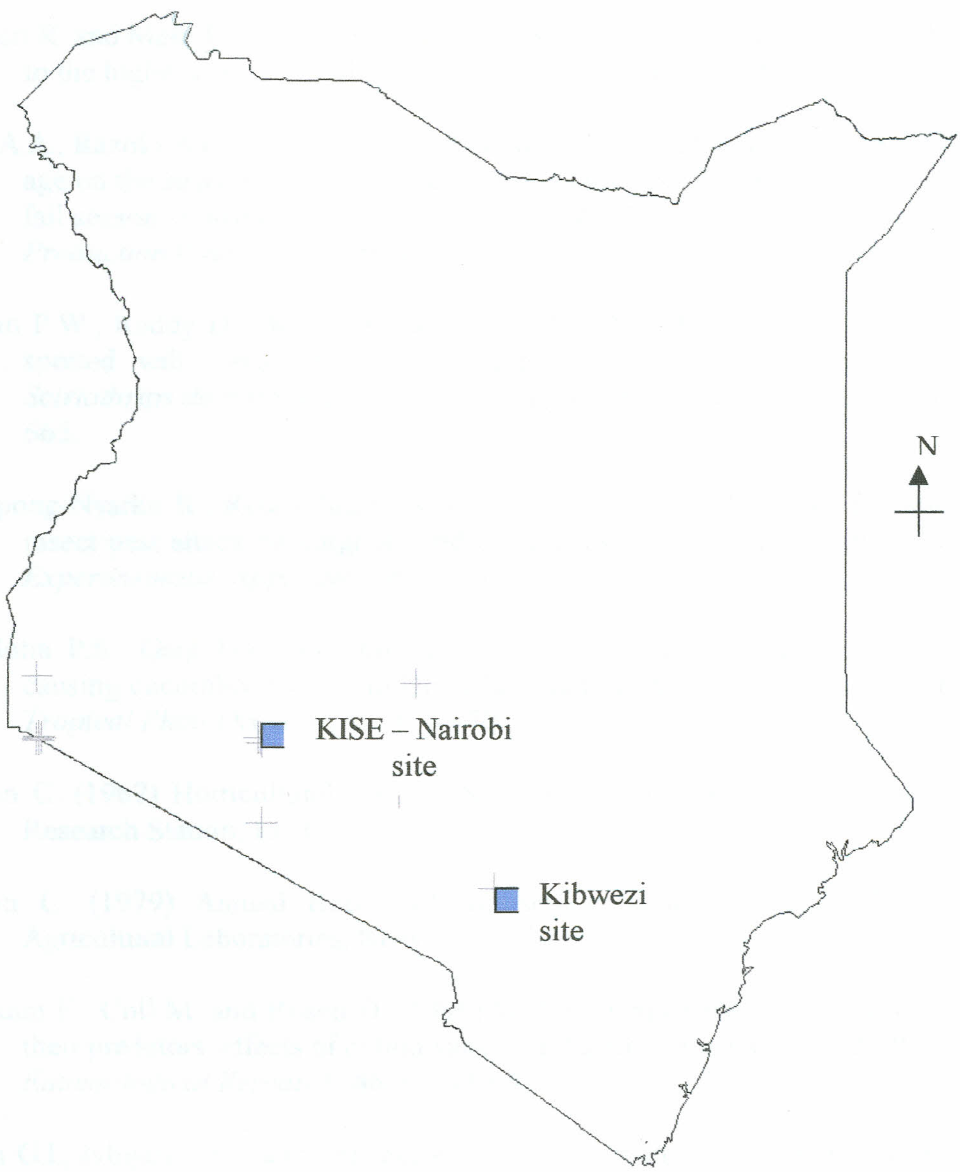
APPENDICES

Appendix 1: Volume of individual vegetables exported from Kenya during 1995

Vegetable	Weight (Kg)
Frenchbeans	14,693,734
Snow peas	2,074,317
Okra	1,898,065
Chillies/ Capsicum	1,580,319
Karella	1384094
Cucumber	119,296
Aubergines	786,845
Snap peas	555,567
Dudhi	421,618
Cabbage	176,956
Onion	340,019
Spinach	110,001
Mushrooms	20,672
Lettuce	9,378
Courgettes	15,045
Ginger	5,517
Cauliflower	5042

Source: HCDA report, 1995

Appendix 2: Map of Kenya showing the study sites



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