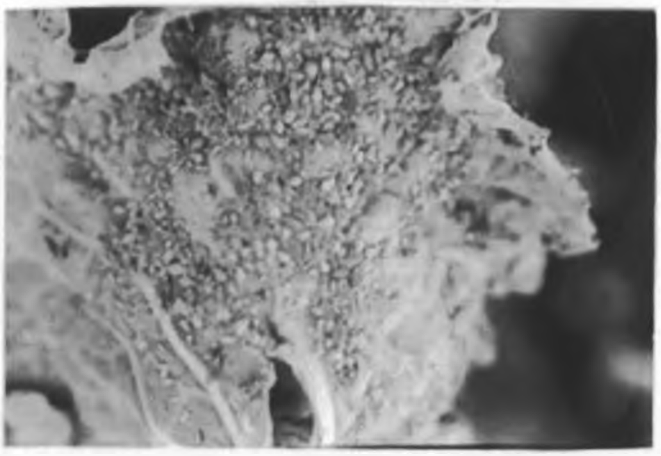
INDIGENOUS BOTANICAL PESTICIDES FOR USE IN INTEGRATED PEST MANAGEMENT (IPM) OF INSECT PESTS OF BRASSICAS BY SMALL SCALE FARMERS IN KENYA



BY

ABDULLAHI DIRIYE KHALIF, B.Sc., MSc.

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A THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN ZOOLOGY (AGRICULTURAL ENTOMOLOGY) IN THE SCHOOL OF BIOLOGICAL SCIENCE OF THE UNIVERSITY OF NAIROBI

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other university.

Signed------------------------ Date---31/5/2007

Abdullahi Diriye Khalif

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

Signed------------------------ Date---6/6/2007

Prof. C P M Khamala, University of Nairobi

P. O. Box 30197, Nairobi - Kenya

Signed------------------------ Date--7·6·07

Dr. R K Day, CABI-ARC

P. O. Box 633 Village Market, Nairobi - Kenya

DEDICATION

This thesis is dedicated to the many Somalis who lost their lives and those who are still under severe trauma caused by the brutality and cruelty of the 16 year old civil war in Somalia. To my late brother, my real friend, my supporter and my example of dignity Omar D Khalif who died while too young. I also dedicate this thesis to Professor C. P. M. Khamala, professor of Zoology and Dr Roger K. Day under whom I had the privilege of doing my doctoral research.

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ABSTRACT

INDIGENOUS BOTANICAL PESTICIDES FOR USE IN INTEGRATED PEST MANAGEMENT (IPM) OF INSECT PESTS OF BRASSICAS BY SMALL SCALE FARMERS IN KENYA

A survey of the knowledge of indigenous farmers in the selected locations of Kiambu, Maragua and Machakos districts in Central and Eastern Provinces of Kenya was carried out to determine their understanding of practical aspects of crop pest management procedures and methods. To test the insecticidal efficacy of the syrup concentrations made from the African marigold plant (*Tagetes eracta*) and of the chilli plant (*Capsicum frutscens*) on the diamondback moth (DBM) (*Plutella xylostella* L.) and the cabbage aphids (*Brevicoryne brassicae* L.), quantities of 300g/1 and 50g/1 fresh aqueous extracts of these plants were prepared in a laboratory and sprayed after 24 hours in kale crop fields against the DBM and aphids. Field experiments to determine the effects of reduced frequency use of chemical insecticides were also carried out alternating with chilli aqueous extracts to determine the effect of reduced use of chemicals by 50 percent on crop yields. Laboratory experiments to determine best dose of chili freeze-dried extracts were carried out by testing various concentrations of chili aqueous extracts for their efficacy against the laboratory reared 3rd instars DBM larvae. Antifeedant effects of the extracts were assessed by introducing DBM larvae on a treated food (leaf). It was found that the farmers in the districts studied had time-tested and in-depth knowledge in farming practices and pest control strategies but lacked knowledge on modern (chemical) insect pest control issues. Repellent effects and insecticidal properties of liquid concentrations of the African marigold plant (*Tagetes eracta*) and of the chilli plant

(*Capsicum futscens*) on diamondback moth (DBM) (*Plutella xylostella* L.) larvae and cabbage aphids (*Brevicoryne brassicae* L.) were observed. The field experiments revealed that both DBM larval intensity and cabbage aphids' scores were significant between the treatments. The effects of the treatments on the actual crop yields varied. Results from replicate experiments showed significant differences in yields between the treatments. Treatments with marigold had a negative impact on the kale leaves in that all the plots sprayed with marigold syrup showed leaf scorching which could have contributed to less crop yield compared to all the other treatments. It was also observed that these botanicals had no impact on the natural enemies of the insect pests and on diseases such as virus and bacterial black rot. Results from the second field experiment for the reduction of the frequency use of diazinon showed that differences in the harvested leaves from the weekly sprayed plots with chemicals were not significantly different from those of the plots sprayed with chemical one week and alternated with chilli in the following week. Drastic reduction of food intake of the insect pests in the laboratory experiment was observed as concentration increased. Repellent effects of the chilli extracts were particularly significant as the concentration increased. However, larval mortality was not significant but it was proportional with the increment of the extract concentration. The combination of repellent effects, antifeedant and stomach poisoning of the chilli extract would make chilli products an alternative strategy on the vegetable insect pest control and could reduce the frequency use of chemicals for environmental safety.

CHAPTER ONE

1.0 GENERAL INTRODUCTION, JUSTIFICATION, OBJECTIVES AND LITERATURE REVIEW

1.1 GENERAL INTRODUCTION

1.1.1 Background, problem statement, justification and objectives of the study

Currently the major components of Integrated Pest Management (IPM) are considered to be the use of selective pesticides, microbial, cultural control and host-plant resistance but botanical product formulations are given less attention maybe because of the required extra activities in plant extract preparation and their quick biodegradability. It is for this reason that this study is designed to explore the efficacy and the potential of some plant products that are not yet conventionally engaged in order to enhance the role of botanicals in IPM strategies.

IPM inventory include

1. Cultural methods or the use of agronomic practises such as crop rotation, crop refuse destruction, tillage of soil, variation in time of planting and harvesting, pruning an thinning, water management, sanitation and fertilisation as well as planting of trap crops.
2. Mechanical pest control methods which include hand picking, exclusion by screens and barriers, traps, suction traps, and collecting machines and crushing and grinding as well.
3. Physical methods such as heat and cold, humidity, light traps and light regulations.

4. Use of biological agents which involve augmentation and release of natural enemies, artificial increase and colonization of specific parasitoids and predators, propagation and dissemination of specific bacterial, viral, fungal and protozoan diseases.

5. Genetic methods such as propagation and release of sterile or genetically incompatible pests.

6. Use of chemical control methods including the use of attractants, repellents, insecticides, sterilants and growth inhibitors.

7. Regulatory methods; this control method involves plant and animal quarantines and eradication and suppression programmes.

Chemical insecticides are the most powerful tools available for use in pest management. They are highly effective, rapid in curative action, adaptable to most situations, flexible in meeting changing agronomic and ecological conditions and are also economical. Despite these impressive credentials much use of chemical insecticides has been ecologically unsound, leading to such disadvantages as insect resistance, resurgence and outbreak of secondary pests, adverse effects on non-target organisms and direct hazards to the user. For these reasons, plant extract pesticides are being sought.

The innovative use of plant extracts by the Kenyan small-scale vegetable farmers could prevent resistance to the common chemical insecticides in notorious insect pests. The use of insecticidal plant products as IPM components would provide consumers safety and high quality food as well as economic supply. This would also enhance sustainability of natural resources and profitability of the producers. The present study aims to experiment these statements and the hypothesis that ***Indigenous botanical pesticides strengthen and***

increase the efficiency of Integrated Pest Management (IPM) for brassicas in small-scale farms in Kenya

Benbrook *et al.* (1996) suggested that the calamity of insect pest control by using chemical insecticides and the unacceptable environmental cost and human and other animal health risks led many people to look for new ways to manage pests. He also explained that instead of seeking strong chemical insecticides and applying them aggressively, some pest control researchers and managers are finding ways to reinforce "nature's bag of tricks" through an approach of Integrated Pest Management.

IPM projects in Africa are few and often follow on single IPM components such as resistant varieties and biological control. Self-financing initiatives on IPM in the continent are scarce and most work on IPM is carried out in projects funded by International donors. As such, in spite of considerable research on IPM that has been already carried out, alternatives to chemical pesticide use to farmers are on a limited scale (Mengech *et al*, 1995).

It is also evident that many research activities contributing to IPM involve control of a single pest organism (Emden and Peakall, 1996) and perhaps two pest control products such as one selective chemical insecticide and one biological control agent or one varietal resistance. This limits strengths of IPM. This study tested the efficacy of two indigenous plant materials, as alternating treatments with pesticides against two major insect pests of brassicas Diamondback moth (*Plutella xylostella* L.) and Cabbage aphids (*Brevicoryne brassicae* L.)

Generally, Brassicas are European origin but are an agriculturally diverse crop that can be grown from the arctic to the sub tropics and also of higher altitudes in the tropics (Hill, 1993). The nutritional value of the *Brassicas* is high even though the composition of the nutrients differs from crop to crop. The leaves of kale are normally prepared as cooked vegetable. The leaves, shoots and stems of the Kale are all considered as part of the food. In terms of nutritional value kales have relatively high levels of calcium and iron as well as vitamin A. In addition they also have fairly high thiamine and ascorbic acid levels in the leaves (Tindall, 1983).

The production of kale is affected by many factors such as soil fertility, diseases and insect damage. Many insect pests attack kale. They include disease vectors, cutworms, some also eat roots, but few defoliate as seriously as Diamondback moth larvae (DBM) do. DBM has now developed resistance to most of the chemical insecticides (Hill, 1993).

Geier (1998) noted the problems of pesticides and explained that the alternative (organic farming), which is the most effective way to reduce chemical pesticide risks, is not utilised. He also mentioned that 25 million agricultural workers in the developing countries suffer due to incidence of synthetic pesticide poisoning in each year. He concluded that IPM may slow down the problem.

Pesticides from plant extracts can reduce the amount of chemical insecticides used for insect pest control (Morallo-Rejesus, 1987). In line with this, farmers who grow brassicae crops in Kenya would reduce environmental contamination as well as the countries' expenditure on importing chemical insecticides by incorporating plant extract insecticides in their IPM programmes.

Farmers have indigenous knowledge of their agricultural production and insect pest control strategies. For collaborating with indigenous farmers and transferring insect pest control techniques to them, it is necessary to understand the social, political, and ecological nature of their agricultural development (Scoones and Thompson, 1994). It is for this reason that a survey of indigenous knowledge to at least address some of these issues became part of this study.

The harnessing of IPM practices by Kenyan vegetable farmers would be highly profitable, since it is the development of a set of practices that regulates and maintains pest population below the economic injury level. The process emphasizes reduction and minimal intervention particularly with synthetic pesticides, and it encourages the natural regulatory mechanism such as bio, cultural and indigenous control systems (NRI, 1991). In concurring with these reports, the tested indigenous plants with insecticidal or repellant properties that can reduce the intensive use of chemical insecticides would be a significant contribution towards a sustainable environment.

From the economic point of view the global losses due to pests, i.e. insects, nematodes, diseases and weeds is estimates to US$ 3 billion annually. This is equivalent to 30% of the potential global food product. In 1988 pesticide expenditure was over US$ 20 billion of which 6.1 billion was for insecticides NRI (1991). Therefore, the results of the present study reveal there is a possibility of the reduction of synthetic insecticide use which would contribute to a reduction of losses due to the heavy expenditure of insecticide use. Therefore, to determine the efficacy of plant products as insecticides and their use in IPM approaches for small-scale farmers in Kenya, this study has been initiated with the following specific objectives:

- To acquire and evaluate local farmers' indigenous knowledge for the control of insect pests of brassicas
- To elucidate the efficacy of the two not yet widely accepted plant extracts namely chilli and marigold against the Diamondback moth (*Plutella xylostella* L.) and the Cabbage aphids (*Brevicoryne brassicae* L.) in kale
- To demonstrate the potential for the reduction of the frequency of spraying chemical insecticides against insect pests of brassicas by using them in combination with botanical formulations.
- To illustrate the efficacy of chilli extracts in the laboratory bioassays.

1.2 LITERATURE REVIEW

1.2.1 Indigenous Knowledge in Farming

Negative aspects of technology transfer and dissemination of information between indigenous farmers and extensionists were discussed by Salas (1994). This was a study based on whether modern science or indigenous knowledge limitations was causing the conflict. The researcher concluded that modern scientific research and researchers without indigenous knowledge input has not significantly improved the life of the peasant farmers, and that peasants' observations are guided by "rich and refined intuitions and contemplative attitudes" (Salas, 1994).

It has been noted that close engagement with farmers is essential and if indigenous farmers' knowledge is at stake then research intervention is crucial to learn more and document findings through practice (Drinkwater, 1994). Long and Villareal (1994) pointed out that farmers are a heterogeneous group and apply different techniques in solving farming problems depending on ecological, socio-cultural, market and economic conditions among other factors. It is therefore necessary to employ the actor-oriented approach in order to understand and acquire their knowledge, so as to develop and transfer techniques that are acceptable to farmers in terms of insect pest control.

Mellis *et al.*(1997) noted that traditional farmers are always suspicious and hesitant of accepting technologies developed elsewhere, and skills and knowledge promoted by agencies or research organisations have often had little impact on technological change in the peasant farmers. But developing technology with farmers rather than for them can increase acceptance and adoption. Involving farmers in any crop protection technology development will encourage adoption of the same technique.

Segura *et al.* (2004) stated that studies on bioecology and management of insect pests have been conducted for decades, yet the rate of adoption of crop protection technology by small scale farmers is very low. It is therefore necessary to know how small scale farmers perceive pests and their natural enemies, and how they try to control them and the techniques they use

1.2.2 The Integrated Pest Management (IPM) in insect pest control

Norris *et al.* (2003) have redefined the IPM concept as follows: IPM has several interpretations, in the beginning it was used to describe the use of insecticides in a way that is compatible with the biological control of insects. And later the concept advanced to the use of integrated control measures. Later IPM was seen to include pest population monitoring, employment of action thresholds, use of bio-pesticides, cultural control measures and judicious use of pesticides. Current IPM concept comprises a) control technologies i.e. combination of cultural, mechanical, biological, genetics and plant breeding and chemical pesticides; b) Pest identification, population assessment and dynamics, pest biology and ecology; c) Economics i.e. crop losses due to pest attack, costs of control measures, crop value and consumer costs; d) Ecosystem i.e. pest resistance, pollution, weather and biodiversity; e) Society i.e. policies and laws regulating pest management and pesticides.

Norris *et al.* (2003) explained the principle IPM strategies used for managing pests, and classified them as follows: a) Prevention, which intends to prevent the arrival and establishment of pests in areas or on the crop that is not yet infested; b) Temporary alleviation, which employs specific control tactics and targets of localised pest outbreaks and is appropriate to apply in smaller areas than larger fields; c) Management of within-field population. This strategy is used when a pest population is well established in the target area and temporary alleviation could no longer provide adequate control; d) Area-wide pest management. This strategy is for up at a regional level to achieve pest population regulation. This strategy requires cooperation of different people with different specialisations such as experts of diseases and mobile insect pests; e) Eradication. This strategy is not agreed among scientists; however, Perkins (1982) called it "total pest management" instead of eradication because of its deficiency in ecological foundation. Nevertheless, scientifically eradication of an organism is an interference of an ecosystem and as such total pest management is considered as a strategy.

Norris *et al.* (2003) explained pest control tactics regardless of the strategy being employed as (a) manipulation of the pest organism i.e. physical influence of the pest organism or altering its behaviour; (b) manipulation of the host plants, a tactic which employs either the increase of crop tolerance or crop change and (c) manipulation of the environment, a tactic that makes the environment less suitable for the pest population build-up while it is more favourable to the pests' natural enemies.

Benbrook *et al.* (1996) also defined IPM as indicating the process for determining if pest management is needed. This process determines when the pest population level becomes intolerable and also when it is necessary to know what level of action should be taken. In IPM it should be clear where and at what frequency treatments should be applied.

In definition, IPM integrates compatible techniques to reduce and maintain pest damage below the economic injury level while decreasing the public health problems and ensuring the safety to nature and the natural environment. Many studies have adhered to the use of pest population regulating factors such as parasites and pathogens while others do research on resistant host plants, while others study the combination of chemical, biological and perhaps cultural control techniques (Benbrook, *et al* 1996).

Rappaport (1992) further explained IPM as a strategy that prevents the increment of insect numbers to levels where quantity and quality of the crop are destroyed, and which develops protection mechanisms of the existing natural controls as well as the combination of cultural practices with carefully chosen sprays.

Harris *et al.* (1998) conducted survey in Kenya and Ghana and found that the use of chemical pesticides was extensive while the use of alternatives was limited. But most farmers in the surveyed area (73% in Kenya and in 83% in northern Ghana) had some knowledge of alternative pest control strategy but the actual use of these alternatives was minimal. The study also found that the alternative pest and disease control techniques were promoted around Nairobi, the use of botanicals and soap solution was available, but in contrast the adoption of these alternatives was negligible.

1.2.3 Effects of the chemical insecticides

Mumford and Stonehouse (1994) stated that broad-spectrum chemical pesticide application is responsible for significant environmental degradation and ecological damage, human health hazards, and the rise of costs of production. Establishments of knowledge-intensive and farmer-based approaches to pest management, and the utilization of novel pest control techniques could be recommendable (Kenmore, 1996; Schillhorn van Veen *et al.*, 1997).

Elwell and Maas (1995) discussed the risks of the synthetic insecticides and demonstrated that apart from human health hazards, chemical insecticides kill natural enemies which dramatically reduce the number of insect pests, chemicals also kill beneficial insects and pollinators such as bees and others. Negative effects of the chemical insecticides to the crop was reported by Smolen *et al.* (1998) that the use of chemical insecticides cause indirect negative effects on the yield, chemicals lower the quality and value of the yield due to poisoning and contamination.

Tillman and Mulrooney (2000) showed the importance of natural enemies and the effects of chemical insecticides on them, and that their conservation is therefore very important. The study states that selective pesticides could play a role in conserving the diversity of natural enemies. Thus this study, as well as assessing the effects of botanicals on the major insect pests, also assessed the effects of both botanicals and chemical insecticides on natural enemies.

1.2.4 Pests

Hill and Waller (1990) described that there are no any other pests that can cause serious damage to *Brassica* crops other than two insect pests and they are aphids which is virus vector and transmit turnip mosaic virus and several other virus specific to Cruciferae. The second insect pest which could cause total defoliation to *Brassica* crops is DBM.

Brown *et al.* (2004) investigated yield loss caused by Flee beetle (*Phyllotreta crucifera*) and some other crucifers insect pests. For this reason the present study collected data on its target insect pests i.e. DBM, aphids and non-target insects such as cabbage sawfly, cabage web-worm, flee beetle, thrips, white flies and bagrada beetle. The study also collected data on diseases and natural enemies.

Diamondback Moth, *Pultella xylostella* (L) (Lepidoptera: Plutellidae) larvae damage the foliage of broccoli, cabbage, cauliflower, collards and related crops. This pest is the most serious pest of crucifers throughout the world (Sorensen, 1993).

Cabbage aphids *Brevicoryne brassicae* L. (Homoptera: Aphididae) are sap-sucking insects which pierce the delicate and unprotected tender leaves, buds and young shoots. During sucking the sap the transmission of viruses do occurs. According to Hill (1993) aphids transmit over 100 virus diseases of plants. *B. brassicae* alone is a vector of 23 virus diseases in the Cruciferae (Hill and Waller, 1990). This aphid species also infests seedlings and causes the seedlings to be stunted and distorted. *B. brassicae* adults may be wingless or winged and always covered with mealy wax which makes the basic colour of green a bit dark. The female *B. brassicae* is parthenogenetic.

Table 1.1: Common insect pests of brassicas

	Common name	Scientific Name	Pest type	Order/Family
1	Cabbage sawfly	*Athalia* spp.	Chewing pest (Larvae)	Hymenoptera: Tenthredinidae
2	Cutworm	*Agrotis* spp.	Chewing pest (Larvae)	Lepidoptera: Noctuidae
3	Diamondback moth (DBM)	*Plutella xylostella* L.	Chewing pest (Larvae)	Lepidoptera: Plutellidae
4	Flee beetle	*Phyllotreta* spp.	Chewing pest (Larvae)	Coleoptera: Chrysomelidae
5	Cabbage web worm	*Hellula undalis*	Chewing pest (Larvae)	Lepidoptera: Pyralidae
6	Aphids	1. *Brevicoryne brassicae* L. 2. *Myzus persicae* 3. *Lepaphis erysimi*	Sucking pest (nymphs & adults)	Homoptera: Aphididae
7	Bagrada Bug	*Bagrada hilaris*	Sucking pest (nymphs & adults)	Heteroptera: Pentatomidae
8	Shield Bug	*Anestatsia* & *Nazara* spp.	Sucking pest (nymphs & adults)	Heteroptera: Pentatomidae
9	Thrips	Different spp.	Sucking pest (nymphs & adults)	Thysanoptera: Thripidae
10	Whitefly	1. *Bamisia tabaci* 2. *Trialeurodes vaporariorum*	Sucking pest (nymphs & adults)	Homoptera: Aleyrodidae

1.2.4.1 The Biology of DBM and cabbage aphids

Sorensen (1993) discussed that diamondback moth adult is about 0.84 cm long, it has wingspread of less than 3 cm and it is grey in colour. Female moths lay spherical, yellowish eggs singly or in groups of two or three on buds, leaves or the stalk of the plant. Eggs hatch after 5 to 6 days depending on the temperature. When the wings are folded three yellowish diamond shaped marks are visible along the back of the male moth.

P. xylostella larvae are green and nearly 1cm long when they are fully-grown. DBM larva undergoes four instars and the larval stage ends after 10 to 30 days depending upon the temperature and food availability among other factors. The larval stage is the damaging stage and consumes all parts of the host plant preferably places around the bud. It is common that larvae feed and make small holes or consume superficially, leaving a thin layer of tissue intact. The larval feeding behaviour causes damage of the reproductive parts of the host plant in which marketable part of the crop will not properly develop. The Pupa of this insect is encased in a gauzelike cocoon and always attached to the leaves or the other parts of the host plant. Pupal stage lasts seven to ten days, although this insect pest overwinters (Sorensen, 1993).

Aphids are soft-bodied insect of 1-2 mm long coloured greenish, dark brown to dark. They reproduce asexually and as their offspring produce asexually, large numbers of aphids are produced within a very short period. Sometimes winged females produce wingless juveniles i.e. nymphs, the juveniles start feeding and sucking the plant saps without moving from the feeding site. The juveniles (nymphs) produce more nymphs such that in five days one aphid can become 100 aphids (Rappaport, 1992).

1.2.5 Management and Control

Jallow and Hoy (2007) recommend a sustainable strategy that results in shifting pest damage away from the harvestable parts of the crop and integrates with multiple (cultural, botanical, biological and chemical) control measures could be preferable to a non-sustainable strategy that kills the pest.

Zhao *et al.* (2006) found that DBM resistance to chemical insecticides is increasing due to lack of suitable alternatives and the unsynchronized use of insecticide classes. The study recommends proactive resistance monitoring and management; it also recommends grower practice such as crucifer-free periods could significantly mitigate the development of insecticide resistance.

1.2.5.1 Diamondback moth (DBM) (*P. xylostella L.*)

Synthetic insecticidal control against DBM failed in recent years and this insect pest is increasingly becoming insecticide resistant and difficult to control. Studies suggested crop rotation and chemical insecticide alternating could reduce the damage of this insect. To reduce DBM damage, plants should also be completely destroyed after complete harvest. Another conventional control method of DBM is sex pheromone traps (Sorensen, 1993).

Several studies on biological control methods against DBM had been carried out at International Centre of Insect Physiology and Ecology (ICIPE) and showed that native species of egg parasitoids occur naturally on this insect pest in Kenya. ICIPE also carried out efficacy evaluation of a new *Bt* product known as Green Guard. The susceptibility of DBM from different ecologies in Kenya for *Bt* product is also under evaluation. Neem product to control *P. xylostella* is also among the control strategies of Integrated Pest Management (IPM) options (ICIPE, 2001).

ICIPE introduced IPM method to farmers that focuses the application of botanical products from Neem (*Azadirachta indica*), which is called the 'tree of over 40 cures' as

Kiswahili language "*Muarubaini*". These products show good control of insect pests and are relatively harmless to natural enemies and non-toxic to mammalians. The action of the Neem products are relatively slow thus the larvae may survive for a few days after application, but their growth and feeding of the larvae are inhibited and the larvae do not cause any further damage. It also has been discovered that Neem products do not have a 'knock-down' effect and take longer to kill the insects or prevent damage compared to synthetic pesticides, thus there is a perception from small scale farmers that the product is not effective.

1.2.5.2 Cabbage aphid (*Brevicorne brassicae* L.)

Control and the killing of *B. brassicae* using insecticides is difficult due to the body surface being covered with wax which repels water (Hill and Waller, 1990). It has been noted that insecticides cannot penetrate the insect body; therefore in achieving a total coverage, additional water may be needed to soften the wax when spraying contact chemical insecticides on this aphid species.

According to Hill and Waller (1990) there are several effective contact insecticides to control this aphid species, among them are Malathion (1.26 Kg/ha) permethrin, primicarb at the rate of 110 g/ha. The spray application should also be directed to the insect especially to the underneath of the leaves where the insects are mainly found at the recommended rate of 700-1700 l/ha.

According to Stoyenoff (2001) apart from chemical control which causes resistance and insect resurgence, cultural control and mechanical control such as plant washing can be practiced for aphid control. Crop residues and cruciferous weeds should be destroyed, while planting a nectar source for beneficial insects and natural enemies of aphids may be helpful.

1.2.6 Efficacy Evaluation of Plant Materials

Saxena (1983) discussed and explained that more than 6000 plant species screened were reported as having insecticidal properties and of these over 2000 products from the plant species were reported that exhibit measurable effectiveness and efficacy against pests. Some of them are Nicotine, Pyrethrum, and Rotenone among others.

Harris *et al.* (1998) discussed factors that affect the adoption of organic farming and use of alternatives among them are the degree of intensification of the farming system, agroclimatic factors, labour intensiveness, negative experiences with agrochemicals, land size and ownership, proximity to urban markets as well as economic factors and limited knowledge. The availability and cost of organic materials and alternative pest control techniques is also among the factors affecting the adoption of this system. Active promotion, advertisements and preferences for agrochemicals are among factors encouraging the use of synthetic insecticides.

Parmer (1993) studied the scope of botanical pesticides in IPM and found that botanicals mainly don't kill the non-target organisms and even though resistant strains can be developed in the laboratory but in wider sense botanicals do not cause pest resistance and resurgence. Botanicals are more compatible with the environmental components than the synthetic insecticides and their degradability by light, heat or even micro-organisms is easier and faster. All these advantages of the botanicals are coupled with their compatibility with various components of IPM.

Hong and Karel (1986) carried out a study testing the efficacy of Neem extracts, hot pepper and tomato leaf extracts on *Ootheca bennigseni* (foliar beetle), *Maruca testulalis* (pod borers) and *Helicoverpa armigera* in the common field bean (*Phaseolus vulgaris* L.). The study accommodated Lindane 20 EC as one of the treatments. The fFindings of the study showed that plots treated with Neem and hot pepper extracts, like lindane gave more effective protection of leaves from the damage caused by *O. bennigseni* than the control and the results showed that the treatments were significantly different from the control plots.

Rappaport (1992) stated that many powerful insecticides can be found in natural products of plants, which can be prepared in the farm by easy and simple methods of crushing, soaking and using as crude extracts. Conventionally approved plant products include Neem, pyrethrum, rotenone, yet many other plants have shown insecticidal properties but are not yet conventionally approved. These include Chilli (*Capsicum* sp.), marigold (*Tagetes* sp.) and Chinaberry (*Melia* sp.).

Isman (1997) observed that several members of the Mahogany family which have important timber species also have appreciable limonoids that have antifeedant and growth inhibitory properties against insect pests. He also observed under laboratory conditions that bark extracts from *Melia toosendan* contain 60-70% toosendanin which is growth inhibitory against insect pests. Isman also found that the effects of this toosendanin were significantly greater than that of pure toosendanin.

Although botanicals may require labour yet their use is very suitable in small vegetable plots and gardens where better harvest from these might conceivably achieved (Isman 1997).

Casida (1983) discussed natural products with potential properties in insect pest control that can replace chemical insecticides. The author established that natural products could be model compounds for researchers as to produce analogues with economic value. The author indicated and argued that further research to determine active components and their synthesis and optimisation the structure of the components is required.

Johnson (2000) discusses that botanical insecticides are promising alternatives as insect pest management, however, botanicals like chemical insecticides have advantages and also disadvantages. Some of the their advantages are their rapid biodegradability, low mammalian toxicity as well as low phytotoxicity, their selectivity and rapid action to stop feeding by insect pests. Their disadvantages include cost and their availability, lack of tested data, and their quick biodegradability could also be a disadvantage since it requires more frequent application as well as timing.

Gaul *et al.* (2002) discussed the advantages in the production and marketing of vegetable and fruit crops when chemical insecticides are not sprayed. The study showed that there is reduction of plant injury and crop destruction, as well as easier harvest management because restrictions of spray application don't apply when harvesting.

Isman (1999) explained that botanical extracts can have insecticidal ingredients that are bio-degradable and environmentally friendly. Mordue (Luntz) and Blackwell (1993) reported that crude formulations of neem seed extract contain liminoids which can have some insecticidal properties. Furthermore, Lowery and Isman (1995) and Naumann and Isman (1996) believe that botanical extract compounds have low toxicity to non-target organisms such as parasitoids, pollinators and predators.

A study of Neemix conducted by Weathersbee and Tang (2002) showed that under laboratory evaluation, the survival rates of *D. abbreviatus* larvae were reduced by neemix due to stomach poisoning and ingestion of treated diet. Notably the neonates were the most affected.

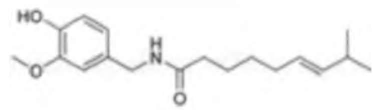
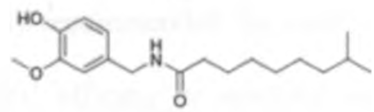
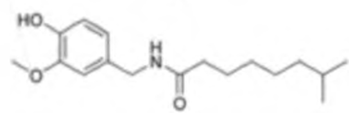
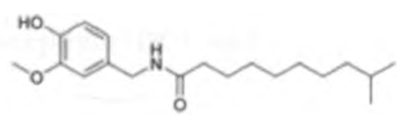
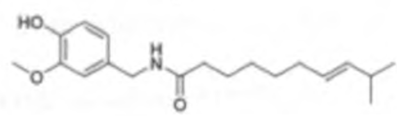
1.2.6.1 Insecticidal activities of Marigold (Tagetes sp.) and Chilli (Capsicum sp.)

Morallo-Rejesus (1987) discussed the toxicity of *Tagetes* sp. particularly *T. erecta* and *T. patula*. The semi-purified extract from *Tagetes* sp. at 3mg/ml sprayed on the leaves of pechay killed 50% of DBM. He demonstrated extract sprayed at 1mg/ml on bush sitao leaves killed 96% of green aphid.

Lale (1992) explained the importance of using chilli as botanical insecticides and urged that chilli can be easily obtained by peasant farmers and this would facilitate their adoption as insect pest repellent.

Morallo-Rejesus (1986) discussed the insecticidal activity of the red paper (*Capsicum frutescens*) in both semi-purified and crude extracts as topical application on DBM larvae and found that these extracts were more toxic than Malathion.

According to Cromie (2006); Dray (1992); Garnanez and McKee (2001); Henkin (1991); Nasrawi and Pangborn (1990) "*Capsaicin* (8-methyl-*N*-vanillyl-6-nonenamide) is the active component of chilli peppers (C*apsicum)*. The ingredient produces a sensation of burning in any tissue it comes in contact with. Capsaicin and several related compounds are called *capsaicinoids* and are produced as a secondary metabolite by chili peppers (five chemical structure below), probably as deterrents against herbivores. Pure capsaicin is a hydrophobic, colorless, odorless, and crystalline to waxy compound. Capsaicin is the main *capsaicinoid* in chilli peppers, followed by *dihydrocapsaicin*. These two compounds are also about twice as potent to the taste and nerves as the minor *capsaicinoids nordihydrocapsaicin, homodihydrocapsaicin*, and *homocapsaicin*. Dilute solutions of pure *capsaicinoids* produce different types of pungency; however, their differences could not be noted using more concentrated solutions. Among its usage Capsaicin is used to deter pests. A common example is the use of ground-up or crushed dried chilli pods in birdseed to deter squirrels, since birds are unaffected by capsaicin. Insects are also affected by capsaicin. The burning and painful sensations associated with capsaicin result from its chemical interaction with sensory neurons. Capsaicin, as a member of the vanilloid family, binds to a receptor called the vanilloid receptor subtype 1 (VR1). First cloned in 1997, VR1 is an ion channel-type receptor. VR1, which can also be stimulated with heat and physical abrasion, permits cations to pass through the cell membrane and into the cell when activated. The resulting "depolarization" of the neuron stimulates it to signal the brain. By binding to the VR1 receptor, the capsaicin molecule produces the same effect that excessive heat or abrasive damage

Capsaicinoid name	Abbrev.	Typical relative amount	Scoville heat units	Chemical structure
Capsaicin	C	69%	15,000,000	
Dihydrocapsaicin	DHC	22%	15,000,000	
Nordihydrocapsaicin	NDHC	7%	9,100,000	
Homodihydrocapsaicin	HDHC	1%	8,600,000	
Homocapsaicin	HC	1%	8,600,000	 "

Parmar (1993) presented a summary of important plants along with their active principles. These include neem *Azadirachta indica* A. Juss, *Melia azadirachta* A. Juss, *Citrus* sp. *Tagetes* sp. *Ageratum* sp. *Annona* sp. and *Osimum* sp. The efficacy evaluation of all these plants and others are already under active investigation all over the world.

Zehnder *et al.* (1997) conducted several studies to compare the effect of the commonly used chemical insecticides with some botanical materials such as garlic juice and red pepper (*capsicum*) powder. The authors were targeting three cabbage insect pest species i.e. diamondback moth (*P. xylostella*), cabbage looper (*Trichoplusia ni*) and cabbageworm (*Pieris rapae*). The cabbage experimental plots were treated with a range of botanicals and inorganic sprays. The findings of these studies showed that the application of botanicals can provide equivalent or rather better control of cabbage insect pests than Karate (Lambda-cyhalothrin; a synthetic pyrethroids).

Ruffinengo *et al.* (2005) studied repellent effects and LD_{50} of essential oils from wild plant species. The study found that only few oils showed repellent effects against mites but none of them attracted mites. However, the study recommended the need of future research to evaluate essential oils and plant extracts' efficacy in repelling mites and insects and determining the LD_{50} of each plant extract.

1.2.7 The Crop: Kale (Brassica oleracea L. var. acephala (DC) Alef.)

Tindall (1983) discussed that this crop originated from Mediterranean, but currently distributed throughout tropic and subtropics. This crop of about 1m height is usually grown as an annual herb in temperate regions, leaves are divided or oval with long petioles, do not form heads as cabbage and blue-green in colour with single robust or branched stems. The suitable altitude of this crop is over 500 m for better growth, but some cultivars can also grow low elevations. As the cabbage crop higher level of organic contents are required in the soil that Kale is to be grown.

For Kale planting; Tindall (1983) discussed that seed is sown in nursery beds and transplanted to rows 45-60 cm spacing whereby between plants are 30-40 cm spacing. This crop requires regular intervals of watering. The study also discussed the growth habit and harvesting time, leaves may be harvested from 50-85 days after transplanting. Yields can be varied from 8-35 t/ha, but the average yields are in the region of 20 t/ha.

Brassica crop production is reduced by insect and disease attack which lower both quality and quantity of the yield (Dobson *et al.*, 2002). On the other hand, chemical pesticides and fertilizers are overwhelmingly overused or misused among the vegetable growers (Harris *et al.*, 1998). Several studies and surveys emphasized that the use of chemical pesticide alternatives was low in Kenya although farmers have some knowledge of alternative methods (Harris *et al.*, 1998).

1.2.8 Field experimenting

Reynolds and Atta-Krah (1986) argued that improved agricultural productions in Africa depend on the exploring and development of the locally available and relevant technology with efficient and acceptable transfer mechanism to move such technology from the research stations to the farmers.

Palada (1986) suggests, "Before any technology is adopted by farmers it must be tested under real farm conditions. The final test for the success of a new technology or innovation is adoption by a large number of farmers in a target area". He suggests research site selection should be carried out and exploratory survey is important to describe the area, this will help to observe and know the area's farming system and identifies target groups of farmers. Site description should carry the information of physical environment and field history, cropping techniques as well as post-harvest practices such as utilisation of crops and crop residue. Experimental designs that are used on-station trials may also be used for on-farm trials, but any specific design to be used will vary according to the complexity of the experiments.

Riley and Pappu (2004) for their study of tactics for the management of thrips, carried out field experimental design using four replicate for four treatments in a randomized complete block design. They recommended this type of block design is relevant and most appropriate in efficacy evaluation trials. The present study therefore concurs with them.

CHAPTER TWO

2.0 FARMERS' INDIGENOUS KNOWLEDGE AND THEIR APPROACH IN INSECT PEST CONTROL IN CENTRAL AND EASTERN KENYA

2.1 Introduction

Awareness by local farmers of the basic botanical products such as the availability of indigenous botanical pesticides, their mode of preparation and application will be increasingly vital in order to accelerate validation of common insect pest control practices. Plants reported to possess some form of insecticidal properties are numerous, and locals use many of these plants, such as Black pepper (*Piper nigrum*), African marigold (*Tagets eracta*), Ginger (*Zingiber officinale*), Neem (*Azadirachta indica*) and Tobacco (*Nicotiana tabacum*) (Harris *et al.,* 1998). Much vegetable crop protection studies using different alternative methods in pest control strategy have been carried out by many institutions. However, issues of developing and scientifically testing botanical insecticides have been given less priority on compared to developing biological control products. This has resulted in farmers and indigenous people to use their traditional ways in insect pest control when the synthetic insecticides failed to solve their agricultural problems.

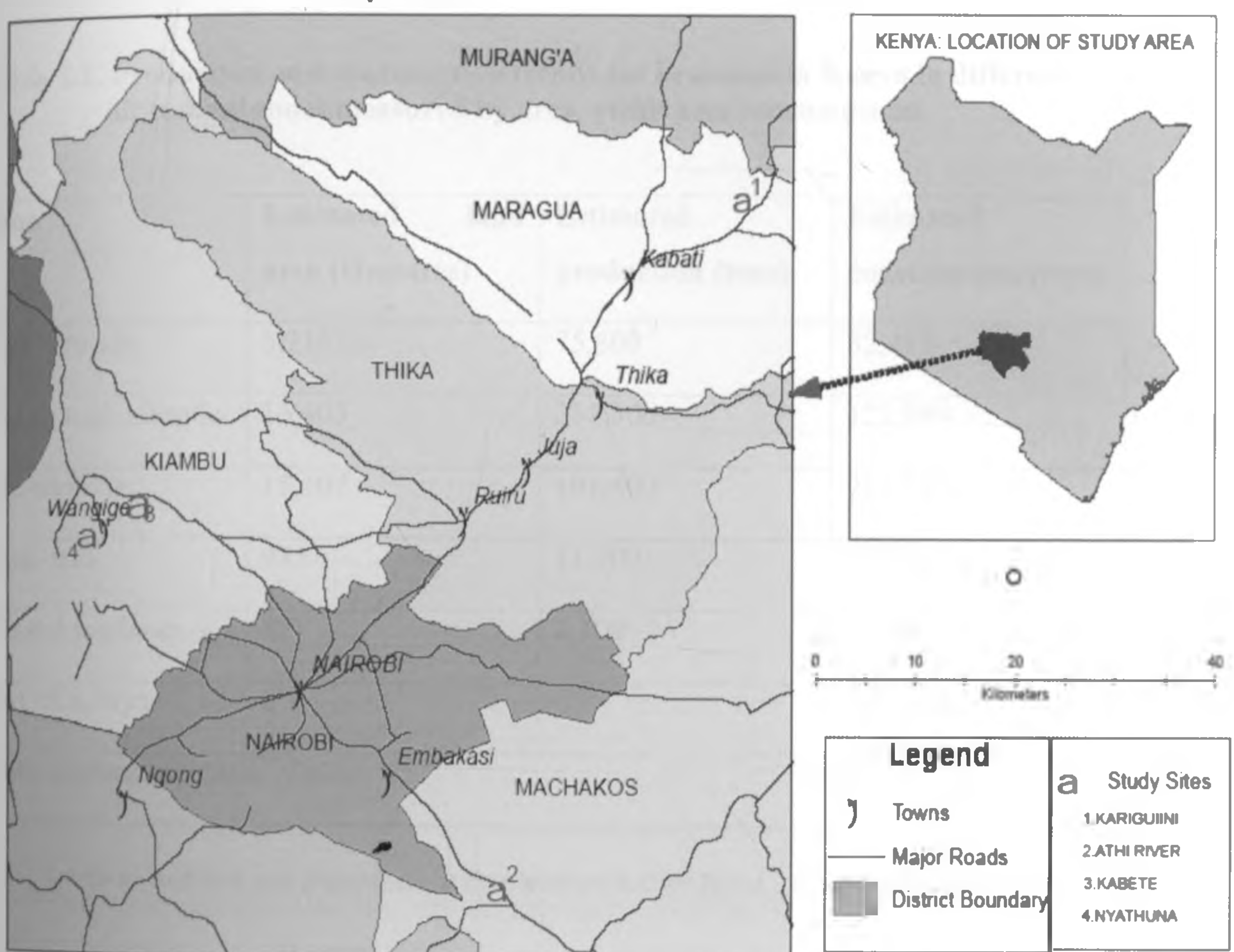
With the intention of obtaining and examining the available farmers' indigenous knowledge in insect pest control and small scale farming techniques, a survey was conducted in four different groups of farmers in Athi-River, Karigo-ini, Kabete and Nyathuna in Eastern and Central provinces in Kenya. The study assessed farmers' perception in organic farming and the indigenous pest control techniques.

Four focus group discussions and 60 individual farmer interviews were carried out during the exercise. The objective of this exercise was: To acquire and evaluate local farmers "Indigenous" knowledge for the control of insect pests of brassicas. To achieve the objective, farmers' experience in organic farming practices, techniques of pest control and accessibility of financial support to the farmers were investigated.

The other aspects investigated which relate to pest control included the individual farmer's personal point of view on chemical insecticides and botanicals were obtained based on the price, availability, safety and toxicity. Every individual farmer was asked to compare chemical insecticides with botanical products in relation to environmental and human health impact, labour requirement, resistance and insect resurgence, biodegradability and residue as well as knockdown capacity.

Communication between farmers and agricultural research practitioners and extension workers is generally poor and limited, because of the directive approach by the extension workers and agricultural authorities. In contrast, indigenous farmers have their day-to-day struggle to establish their own knowledge on insect pests and crop protection techniques (Scoones and Thompson 1994, Segura *et al.*, 2004). Improving communication between research institutions and peasant farmers can contribute to effective insect pest control as well as enhancing indigenous pest management techniques.

Study Area



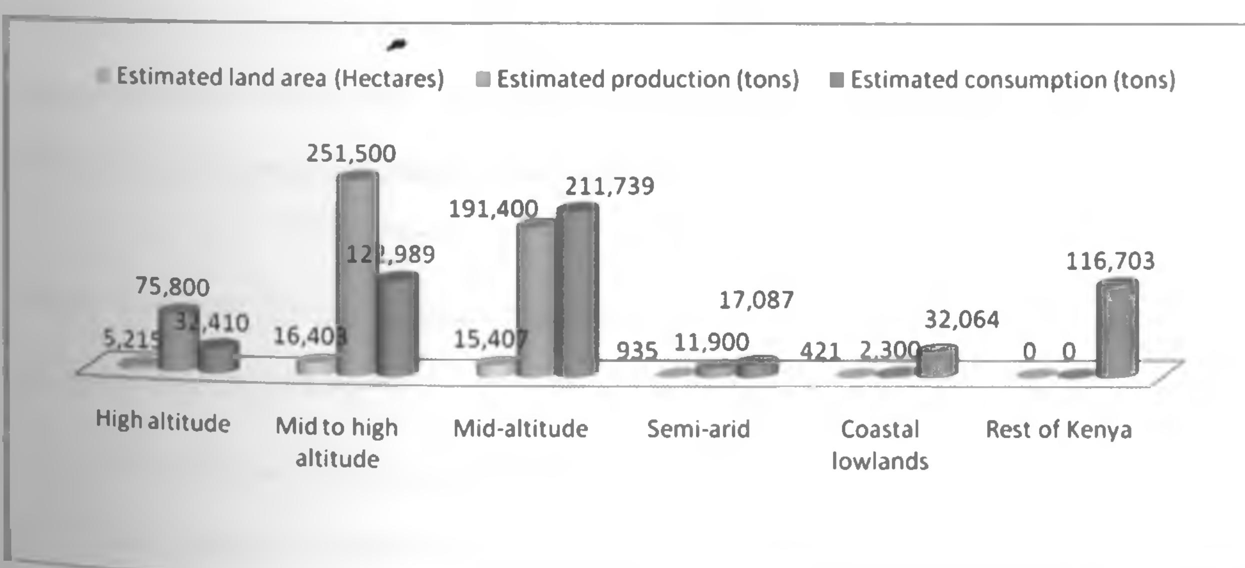
Study area: Map of Kenya showing area of this study

Semiarid and high altitudes with different agro-climatic conditions in Kenya produce vegetable crops. The major vegetable producers, specifically brassicas, predominate in the high and mid-altitude areas in Kenya (Jaetzold and Schmidt, 1983) (Table 1.2)

Table 2.1. Production and consumption trends for brassicas in Kenya in different altitudinal zones measured by area, yields and consumptions

Zone	Estimated land area (Hectares)	Estimated production (tons)	Estimated consumption (tons)
High altitude	5,215	75,800	32,410
Mid to high altitude	16,403	251,500	122,989
Mid-altitude	15,407	191,400	211,739
Semi-arid	935	11,900	17,087
Coastal lowlands	421	2,300	32,064
Rest of Kenya	0	0	116,703

From Kamau and Mills (1998)



Relationship and interactions between zones, production of brassicas and consumption levels in Kenya.

2.2 Materials and methods

2.2.1 Survey Strategy Setting

Before conducting the farmer survey, a timetable of the survey and plan of action were drawn, and the following activities were carried out:

a) Intensive literature review was carried out to determine the available farmers' indigenous knowledge

b) Two survey instrument i.e. (i) focus group discussion checklist and (ii) individual farmer interview questionnaires were constructed.

c) The survey to assess farmers indigenous knowledge assessment in insect pest control methods was then carried out

2.2.2 Site selection

Pre-survey meetings were carried out with CAB International staff who were already working with the farmers in the study area (Fig 1.1). Areas to be covered and logistics required were discussed in detail, type of farmers that would be visited and the crops they grow had been discussed and a duration and timetable of the survey were agreed.

Farmers from four different locations were selected as the target group, and they were consciously selected due to:

1) The techniques they use as insect pest control practices
2) Their vicinity in Nairobi area
3) Their predominance of vegetable production

2.2.3 Profile of the selected farmers groups

Athi River Bank Farmers Group: The group is located at Athi River town in Movoko location of Machakos district in Eastern Province in Kenya. The group members live in Athi River and farm along the riverbank. The group consists of 14 members 8 of whom are women. Farmers only use chemical insecticides as a means of insect pest control.

Karigu-ini Organic Group (KOG): Covers Githurai sub-location under Gaichanjiru location in Maragua District of Central Province in Kenya. The group consists of 30 members 18 of whom are women. KOG members practice entirely organic farming covering fertilizers, pest control and other farming practices. Kenya Institute of Organic Farming (KIOF) trained this group and presently the group is knowledgeable about how to search, prepare and mix botanical products as fertilizers and insect pest control products.

Kinga Dairy Farmers Group: Members of this group are mainly from Kabete location in Kiambu division while some from Nyathuna in Central Province of Kenya are also members of the group. The group consists of 50 members 34 of whom are female and 16 are male. This group uses both chemical and botanical products as pest control products.

Kili Organic Group: This Group covers Nyathuna and Tegoni locations in Central Province of Kenya and has 18 members of whom 5 are women. This group has the lowest proportion of female members of the four target group farmers in this study. The group is very effective and democratic in group decision making. They vote when decisions have to be made and apply on 2/3 majority vote. The insect and disease control strategy of this group is entirely botanical and cultural. The group doesn't use any chemical pesticides or synthetic fertilizers.

2.2.4 Visits and approach of the Interviews

The day before the survey started every location was informed on the time of the survey. Prior to starting the focus group discussion and individual farmer interviews, meetings with the area agricultural extension officer/s were conducted and explanation was given to the relevant agricultural authority. Area field extension workers explained about the extension activities in the area and existing insect pest control strategies, the role of their office as well as the link between them and farmers. And similarly farmers were briefed and informed about the objective of the visit (Plate 1.2).

2.2.5 Focus Group Discussion Method

A detailed checklist for focus group discussion was constructed (Annex 1). The questionnaire was divided into six sections to ensure that each was appropriate for and understandable by farmers. The first section requests background information of the farmers and the crops they grow. The second section deals with the current approach in insect pest management used by the farmers. Sections three and four cover the basic questions of the study. Section five covers group's experience in using botanicals with particular focus on chilli and marigold and their effectiveness compared to chemical insecticides. And section six covers impacts of chemical insecticides in terms of human health. Section one and two of the questionnaire includes mainly closed-ended questions

(questions that need yes or no or one number) while sections three, four, five and six include open-ended questions (questions that require detailed answers rather than yes or no).

After farmers provided information of the section one, two, five and six they were asked to thoroughly discuss the basic question of the survey: ***Why are the farmers using what they are using and why are they not using what they are not using in insect pest control?*** Using a discussion method, they also discussed their experience in using botanicals, mainly chilli and marigold, and thoroughly diagnosed the problems and illnesses that the chemical insecticides cause during their preparation and applications.

To avoid any communication barriers farmers were allowed to speak their local and indigenous language. Two technologists from University of Nairobi Department of Zoology and CAB International who understood the local Kikiuyu and Kamba languages were accurately following the discussion of the groups and taking notes translated in English. In case of any difficulties for some scientific names of pests and products the technicians helped farmers (Plate 2.2).

2.2.6 Individual Farmer Interview

Farmer interviews were conducted using a single visit interview method. The survey was conducted by personal interviews with a sample of 60 farmers in four locations (Table 2.2, Plate 3.2). An individual farmer interview questionnaire (Annex 2) was used, completing specific questions on comparison between botanicals and chemicals were asked to each farmer. Each farmer was asked whether he/she uses botanical products such as chilli and marigold, and asked to compare botanical products with chemical insecticides in terms of price, availability, safety, toxicity, environmental and human health impact, labour requirement, resistance and resurgence, their biodegradability and residue, knockdown capacity against insect, farmer's knowledge of both chemical and botanical pesticides and legal requirements of both products.

Table 2.2: Number of farmers interviewed with in respective locations

Area	No. Farmers interviewed
Athi-River	11
Karigu-ini	18
Nyathuna	14
Kabete	17

Completed questionnaires were reviewed to ensure consistence response, and completeness as well as for error checking.

Plate 1.2. Explaining the objectives of the indigenous knowledge assessment to the farmer. Showing one of the research assistants is explaining to the farmers the objectives of the extension activities, existing insect pest control strategies and the role of researchers as well as the link between researchers and farmers at Kabete location

Plate 2.2. Focus group discussion during the indigenous knowledge assessment. The groups is discussing brassica crop reduction due to insect and diseases infestations, effects of chemicals on human health, and the over use and misuse of both insecticides and fertilisers

Plate 3.2. Individual farmer interview during the indigenous knowledge assessment. The principle researcher filling individual questionnaire from the Kabete farmers

2.3 RESULTS

2.3.1 Gender issues in smallholder farm operators in the four locations

It is common that in small-scale farms which are run by the owners, many tasks fall on the female members of the family. The four studied groups accommodated 112 members and only 60 (54%) of them who were individually interviewed. Sixty Five (65) of the total number were females, thus the percentage of the female farm operators was 58% (Figure 1.2). The female respondents to the individual farmer interview constituted 65% (39 members) while 35% were males.

Internal dynamics of effective communities can be determined by the role that gender plays in that community. In the sub-Saharan communities it is common that land tenure system is male based (Tobisson 1993). However, results from the present study showed that the study area is characterized by female farmers. Furthermore, during the interview it was found that all these female members were the owners of their farming lands.

2.3.2 Agronomic practices

All the farmers interviewed grow Cruciferae crops (mainly kale and cabbage) for both household consumption and commercial use. Fifty percent (50%) of the farmers interviewed use entirely botanical farming while the other 50% don't (Figure 2.2). Similarly, 48% of the total number of farmers interviewed use chilli and marigold among other botanicals as insect and disease pest control products (Figure 3.2).

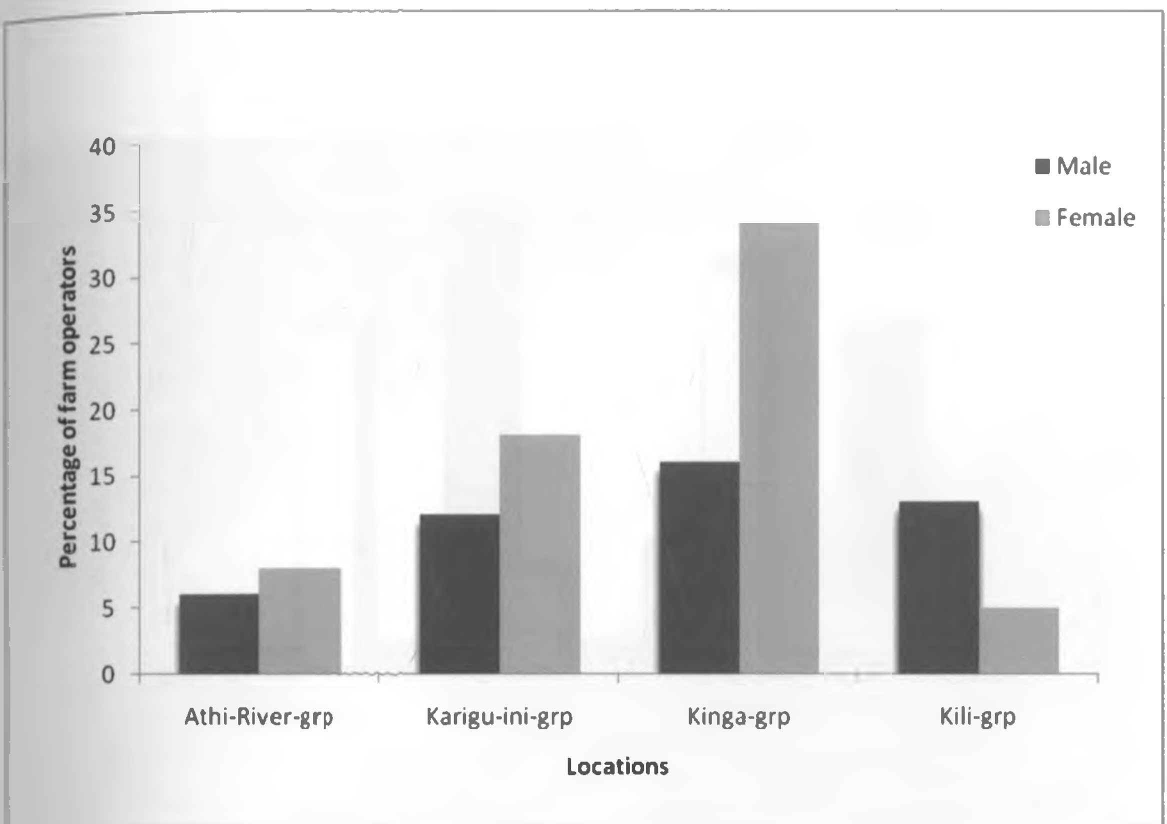


Figure 1.2: Female/male ratio for the visited four groups. The graph shows that Female farmers are more than male farmers in Kinga, karigu-ini and Athi-River groups, while Kili groups was male dominant

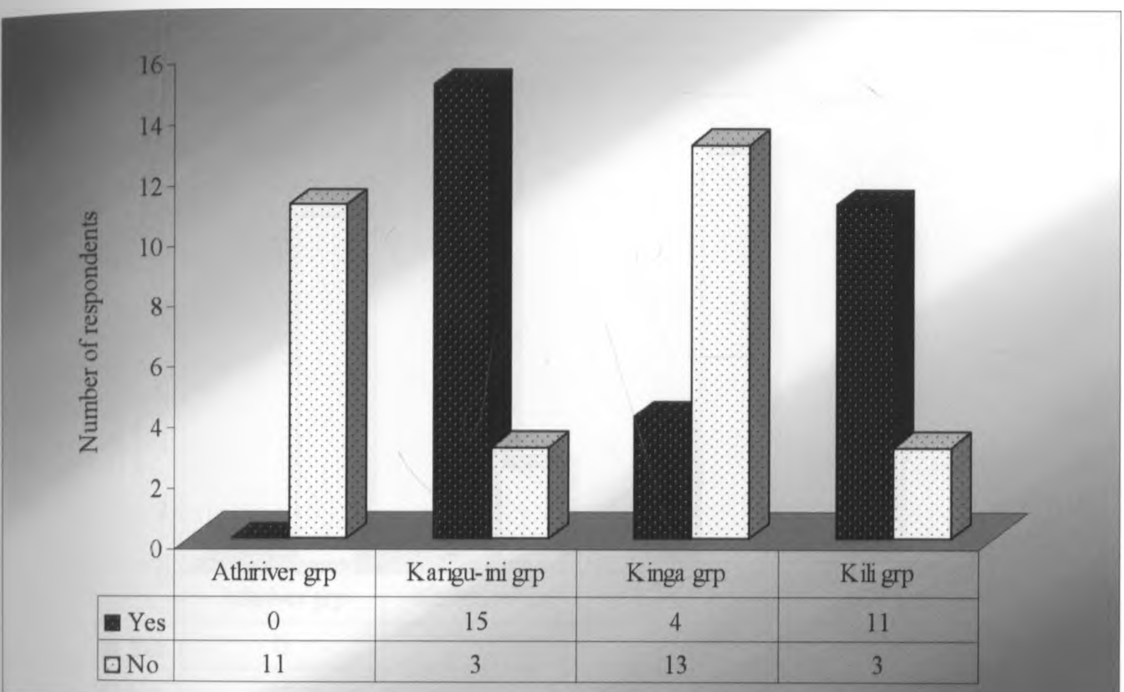
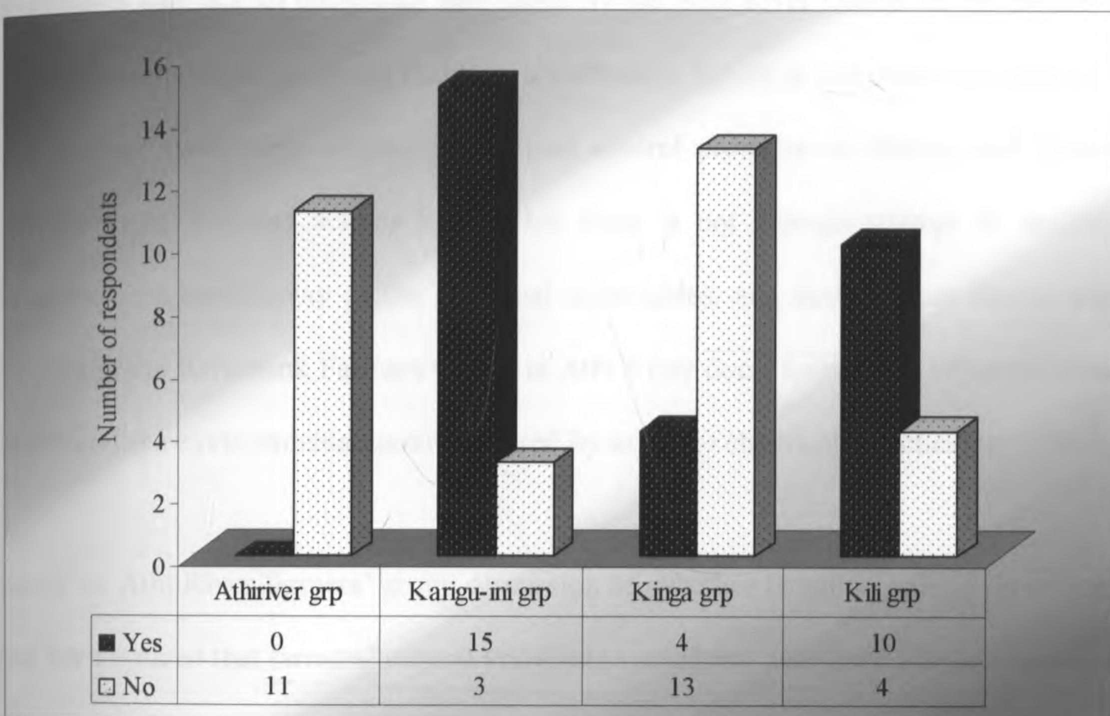


Figure 2.2: Comparison of farmers who use botanical farming and those who don't use. (Kili and karigu-ini groups use botanicals more than chemicals while Athi-River and Kinga groups used synthetic insecticides more than botanicals)



	Athiriver grp	Karigu-ini grp	Kinga grp	Kili grp
■ Yes	0	15	4	10
□ No	11	3	13	4

Figure 3.2: **Farmers who use chilli and marigold as insect pest control products compare to those who don't use.** (Karigu-ini and Kili group use chilli and marigold more than synthetic chemical insecticides. Athi-River group don't use chilli and marigold)

2.3.3 Rationale for using botanicals with particular interest in chilli and marigold (insect pest control practices and challenges felt by the farmers)

In the focus group discussion, limited knowledge of the indigenous pest control procedures and lack of botanicals was raised by the Athi River Group. In the process of the discussion the group agreed that they are naturally forced to use chemical insecticides due to their availability, display of the pest control products on shelves and constant advertisement. Farmers acknowledged that there is not enough attempt to challenge advertisement and display of the chemical insecticides, and due to these factors many farmers in the Riverbank Farmers Group in Athi River don't know their effect on human health and the environmental hazards caused by usage of chemical insecticides.

Based on Athi River farmers' group discussion on whether botanicals are toxic or not, it had been noticed that farmers' current knowledge could not determine whether botanicals are more toxic than chemical insecticides. One main issue that forced this group to use chemicals was that they grow vegetables on commercial basis and thus they require high yields to sell. Some of the group members believe that chemicals are very effective against vegetable pests and not harmful to humans. Among chemical insecticides that Athi River group uses are: Punside, Karate, Dimethoate, Diazinon and Malathion. They believe that chemicals are cheap and they receive advice from their group members. The group believes that using readily available chemicals is easier and doesn't need much education, unlike biocontrol.

Riverbank Farmers Group in Athi River discussed about when intervention of insect control is required and their suggestion was that they start spraying chemical insecticides immediately after seedlings are transplanted without determining pest population. Farmers emphasized their limited knowledge about insect pest monitoring and forecasting during their discussion. It also became clear that most of the farmers have no knowledge about scouting and other methods of measuring insect damage.

Karigu-ini Organic Group (KOG) members entirely practice organic farming including fertilizers, pest control and other farming practices. Kenya Institute of Organic Farming (KIOF) trained this group and presently the group is knowledgeable about preparation and mixing botanical products as fertilizers and insect pest control products. Focus group discussion and individual farmer interviews revealed that the group members don't know whether botanicals cause any resistance or not. Botanicals are more available than chemicals according to KOG because chemicals require money to buy but to get botanicals one need only to walk around one's small farm and pick them without involving any expenditure. KOG expressed that botanicals are cheap, safe to use, don't pollute the environment and safe to beneficial insects compared to chemical insecticides

KOG use botanicals for pest control because they believe that botanicals do not kill natural enemies such as ladybird beetles, which are killed after spraying chemical insecticides. Members of this group were aware that chemicals are toxic and farmers experienced of wounds in the fingers and feet, other illnesses including coughing and difficulty in breathing after inorganic insecticides spraying. Curing these illnesses takes longer than usual. Group members believe that inorganic fertilizers interfere with soil structure while chemical insecticides kill beneficial organisms like earthworms and others in the soil.

Kinga Diary farmers Group showed enthusiasm about the strategies of pest control using bio-pesticides. The use of *PxGV* attracted farmers' interest, and questions about the life-span of the virus, if it is selective to DBM, its spray frequency, the virus's site effect to the natural enemies and difference between spraying the virus and other sprays were discussed.

The group explained how cutworms are destroying their crop, and group members tried indigenous control methods such as digging near the roots of the plant and removing the pest from the soil. Some also explained that ash and hot water could be put near the roots. Apart from cultural and indigenous control methods against cutworm, spraying Karate during the evening can control cutworm invasion. Members of the group discussed about the problem of birds but some of them shared their experience in bird control with the other members and they explained that if the farmer gives a section of the farm to birds then most likely birds only remain feeding in that part and never invade the rest of the farm.

Most of this group's members use synthetic insecticides as insect pest control strategies but those who use botanicals believe that Mabangi (African marigold; *Tagetes eracta* as a repellent) is an indigenous plant which many farmers use for insect pest control. Caterpillars of different insect pests are the major pests in the farmers' vegetable farms.

Farmers mainly use mechanical control for caterpillars such as handpicking and crashing them.

Kili Organic Group grows brassicas among other crops and currently the group is looking for a common garden for demonstration. The group members have contributed money for the demonstration plot. The group has been trained by KIOF and they rely on the knowledge they acquired from KIOF. The group uses botanicals and they don't want to kill insects but repel them and want insects to die naturally in order to preserve the environment. As with most of the other groups, members of this group believe that chemicals can cause many sicknesses such as allergies, stomach upset, headache, wounds and breathing difficulties among others. During the discussion on whether botanicals could pollute the environment, the group agreed that botanicals do not pollute the environment.

2.3.5 Farmers' perception of botanical insecticide efficacy

Although farmers knew that botanicals could play a role in insect pest management and have potential to control insect pests, Nyathuna (Kili organic group) group which entirely uses botanicals believed that they are not better than chemicals in insect pest control. Karigu-ini group members who are also botanical users believe that chemicals can do better in controlling insect pests than botanicals. 72.73% from Athi River group, 72.22% of Karigu-ini Organic Group and 50% from Kili Organic group assume that chemical insecticides are better than botanicals as insect pest control products (Tables 3.2).

Group and individual farmers' discussions and interviews emphasized that although chemicals could be as good as botanicals or can even do better in insect pest control, chemicals per se can cause environmental pollution, skin sicknesses and water contamination (Table 2.3). Therefore, in order to avoid environmental and human health hazards, many farmers opted to use botanicals.

Table 2.3 Comparison of botanical products with chemical insecticides by 60 interviewed farmers in terms of insect resistance, killing capacity, farmers' knowledge in applying and preparing and well as required labour input

	Labour intensively			Insect Resistance		
Location	% Chemical	% Botanical	%(No idea)*	% Chemical	% Botanical	%*(No idea)
Athiriver	0.00	90.91	9.09	54.55	18.18	27.3
Karigu-ini	0.00	94.44	5.56	72.22	11.11	16.7
Kinga	11.76	17.65	70.59	29.41	11.76	58.8
Kili	0.00	78.57	21.43	85.71	7.143	7.14

	Knockdown Capacity			Farmers Knowledge		
Location	% Chemical	% Botanical	%*(No idea)	% Chemical	% Botanical	%(No idea)*
Athiriver	72.73	0.00	27.27	100.00	0.00	0.00
Karigu-ini	72.22	27.78	0.00	22.22	77.78	0.00
Kinga	29.41	5.88	64.71	70.59	11.76	17.65
Kili	50.00	50.00	0.00	21.43	78.57	0.00

Table 2.4: Comparison of botanical products with chemical insecticides by 60 interviewed farmers in terms of price, availability, toxicity and environmental hazards

	Price (More expensive)			Availability (more available)		
Location	% Chemical	% Botanical	% (*no idea)	% Chemical	% Botanical	% (*no idea)
Athiriver	72.73	0.00	27.27	90.91	9.09	0.00
Karigu-ini	94.44	5.56	0.00	38.89	61.11	0.00
Kinga	70.59	11.76	17.65	29.41	58.82	11.76
Kili	92.86	7.14	0.00	14.29	85.71	0.00

	Toxicity (More toxic)			Environmental Hazard		
Location	% Chemical	% Botanical	% (*no idea)	% Chemical	% Botanical	% (*no idea)
Athiriver	90.91	0.00	9.09	90.91	9.09	0.00
Karigu-ini	100.00	0.00	0.00	100.00	0.00	0.00
Kinga	70.59	0.00	29.41	70.59	0.00	29.41
Kili	100.00	0.00	0.00	100.00	0.00	0.00

Almost every farmer interviewed consented that chemicals are more toxic than botanicals (Table 4.2). Hence, the question will be "if all indigenous farmers believe that chemicals are more toxic than botanicals, then why the use and excessive use of chemicals are increasing"? Most of the groups did agree that chemicals require less labour than botanical application and also chemicals are more available; while botanicals are less readily available.

All members of the farmers groups interviewed asked researchers and research organizations why they do not do more research work on botanicals, or if they do why they just shelve their findings? All the interviewed members believe that top-down technology is not appropriate and they prefer that researchers do work with farmers in order to promote the adoption of the technologies and dissemination of information.

2.4 DISCUSSION

The small scale farmers who depend on Kale crop for subsistence, consumption and commercial benefits were knowledgeable about damage caused to this crop by insect pests. Although they were aware that the damage could be reduced by the application of synthetic insecticides, they had little knowledge about botanical pesticides. It appeared that through effective awareness, these farmers could produce their own botanical pesticides which would be cheaper to enable them gain more value from their kale crops. This would add on to what they are already using including the indigenous plant concoctions, use of wood ashes, hot water and hand picking to control insect pests. Some farmers even use fresh milk to control some plant diseases. Apart from traditional and indigenous techniques in pest control, some other farmers employ purely chemical control method to eliminate insect pests while some others believe that repelling insects is better than killing them.

The survey revealed that farmers who use synthetic insecticides heavily are those who plant kale and cabbage for commercial purpose. In addition to botanical pesticides use by the local vegetable farmers, the survey documented farmers' knowledge and practices in organic farming. Most of the farmers have knowledge about the insect pests attacking their crops but have little knowledge of the economic threshold levels and the appropriate time of when to apply insecticides.

Results from the present study revealed that many farmers don't have adequate knowledge on proper use of chemicals and raises the need for farmers to be educated on the proper use of chemicals. The present study also agrees with Banjo *et al.* (2003) study, which revealed the danger caused by insect pests to horticulture crops while traditional insect pest control alone cannot be enough, and many farmers are still unable to afford chemicals and don't know the correct use of them.

The development of any effective managerial system needs the increment of the amounts of general and indigenous knowledge. This could be reached through the integration of scientific researchers' findings and knowledge of generalist practitioners and commitment of implementing the new forms that allow many issues to be integrated Marsden (1994). The indigenous farmers surveyed revealed that with more research on the integration of the existing indigenous insect pest control strategies with the modern technology, many small scale farmers would benefit greatly from research and technology.

It was evident that the farmers' economic constraints together with the human health and environmental hazards caused by the application of chemical insecticides, the use of naturally occurring plants with insecticidal properties is highly essential. This was clear from the farmers' acknowledgements when asked about the use of indigenous insect pest control strategies and how may greatly contribute to the enhancement of scientific knowledge.

However, the present study acknowledges, awareness, information sharing and response to the experience of farmers are much more important than top-down technology transfer, if the ultimate goal is to attain the use of safe products as insecticides with particular emphasis on botanicals and increase natural crop protection practices.

Current modern methods and indigenous knowledge in insect pest control practices and scientifically tested plant products have to be synchronized. It is also important to improve practical application of the potential and conventionally accepted plants with insecticidal properties to a standard acceptable and accessible by the farmers and users.

Experience shows that technologies that scientists and research organizations develop without farmers' involvement are often not adopted by the farmers, because farmers believe the technology doesn't meet their needs or address their constraints (Jonfa, 1996). The present study, however, recommends that researchers should involve farmers in their botanical research priorities. Farming communities could play a central role in horizontal spread of the natural and botanical pest control concepts.

In terms of farmers' ability for buying agricultural inputs (pesticides), virtually all respondents highlighted their financial limitations. Taking into consideration of chemical insecticides' health and environmental risks as well as the limited knowledge of their applications and preparations by the farmers, provide better argument and line of reasoning for strengthening studies on botanical products as a strategy of insect pest control.

CHAPTER THREE

3.0 FIELD EVALUATION OF THE EFFECT OF CHILLI AND MARIGOLD AQUEOUS EXTRACTS ON DIAMONDBACK MOTH (*Plutella xylostella* (L)) AND CABBAGE APHIDS, *Brevicoryne brassicae* (L) IN KALE FIELD

3.1 Field Experiment

3.1.1 Introduction

Tripp and Ali (2001) concluded in their study that natural pest control products may be effective alternatives to conventional pesticides. However, they also argued that these products deserve further research and some other issues such as environmental consideration, commercialization of the products and establishment of their sustainability and the mode of preparation and application be considered. Therefore, the present study emphasized chilli and marigold as botanical alternatives to synthetic chemicals and also documents some of their negative impacts to plants.

Chilli and Marigold extracts are among plant aqueous products that could be used as pesticides. Organic agriculture and use of botanical pesticide products are becoming important globally. Due to this interest, consumers prefer obtaining organically produced vegetable and other important greens. This will open a market opportunity for vegetable producers and small scale farming practitioners. However, only a small percentage of vegetable farmers practice organic farming in Kenya.

Naturally, some plants produce their own products for defense which act to inhibit pest attacks and many plants produce various alkaloids and active principles. The use of these plant materials started since time in memorial and has continued to the present and many of these products are acceptable in organic farming (Bettolo, 1983).

There is a growing interest in researching on botanical pesticides due to their insecticidal, repellency and antifeedant properties. Some of these plants are locally available. Their accessibility and easy preparations and applications, possibly reduce excessive use of synthetic insecticides

The repeated and frequency use of synthetic insecticides by small scale farmers have caused many vegetable insect pests to become resistant to many pesticides. This is an enormous problem that may cause insect resurgence; secondary pest outbreaks and pesticide treadmill which result sever destruction of the ecosystem.

Due to the above experiences and in order to evaluate the susceptibility of DBM and Cabbage aphids to botanical formulations as insecticides, field trials were performed in 2002 with the following specific objective, namely, to determine efficacy of two plant extracts, i.e. Chilli and Marigold against the Diamondback moth (*Plutella xylostella* L.) and Cabbage aphids (*Brevicoryne brassicae* L.), the major insect pests of brassicas.

The Diamondback Moth, *P. xylostella* (L.) (Lepidoptera: Plutellidae) is the most important insect pest of cruciferae crops, and serious infestations may cause total defoliation of kale plants. Similarly, aphids damage a wide variety of plants. Controlling DBM and aphids is problematic since these pests are resistant to many synthetic insecticides (Mengech *et al.*, 1995, Leatemia and Isman, 2004, Stoyenoff, 2001).

3.2 Materials and methods

3.2.1 Study site

Two field experiments were carried out to test the efficacy of aqueous preparations from chilli and marigold plants in the control of two common insect pests of kale namely DBM and cabbage aphids. During the experiments, requirements for good organic practice were applied. These included soil drenching during sowing and transplanting, preparing good seedbeds, proper husbandry of the nurseries, controlling diseases such as damping off and proper watering.

Both 1st and 2nd phases of the field experiments were carried out at Kabete, University of Nairobi's Agricultural Research Farm. The chosen experimental site is in the upper midland agroecological zone. The altitude of the site is about 1300-1500 meters above sea level. It has annual rainfall of 900-950mm occurring in two rainy seasons in the year; long rains (March-June) and short rains (October-December). The average annual temperature of the chosen site is 19.7-20.7^{0}C. (Jeatzold and Schmidt, 1983).

Kabete site was also suitable site because residents of the area grow kale and cabbage as cash crops. Consequently, kale insect pests of economic importance are abundant in the area. Some farmers in this area are organic farmers who use botanicals as pest control strategies, while many use synthetic chemicals.

3.2.2 Kale planting

3.2.2.1 Sowing seeds

Experimental plot preparation was carried out and it included, early and deep digging using a tractor to expose soil insects such as cutworms to natural enemies, and to eliminate soil-borne diseases as well as ensuring proper seed germination.

Seeds were purchased from registered seed companies in Kenya. Nursery preparations were carried out after disinfecting and ploughing the experimental site. Kale in the tropics are generally transplanted using seedlings. Cow manure bought from Kabete animal farm and DAP (Diammonium Phosphate) was applied as fertilizers. Watering seeds was carried out on a daily basis to ensure proper seed germination. The seedlings were transplanted when they were about 100mm tall. Spacing between rows at the transplanting site was 60cm while spacing between plants was 40cm.

For sowing the kale seeds, seed beds of 2 x 1 m^2 were built. Seedbed soil was made loose, and seed drills about 20cm apart were lined about 2cm deep. All the seedbeds were disinfected in the rows with Monceren T Pencyron + Thiram (4g/1litre) to prevent soil-borne diseases such as *Rhizoctonia* spp. and *Pythium* spp.. Seeds were then thinly distributed in the rows and covered gently with soil. Seedbeds were protected from direct sunlight by putting 1.20m high frame and were covered with grass. To ensure that the soil always remains moist seedbeds were watered twice every day (in the morning and evening) and weeds were regularly removed by hand. Seed germination was regularly monitored and no insecticides were used after seed germination.

3.2.2.2 Transplanting

Seedlings of kale were transplanted in rows with a plant spacing of 40 cm and 60 cm between rows. Transplanting started after one week of hardening the seedlings by only watering once every day instead of twice. Seedlings were transplanted to a prepared site of 22.7m x 17.9m five weeks after germination.

Transplanting was carried out in the evening to avoid wilting of seedlings, to a thoroughly watered prepared field site. Prior to transplanting seedlings, holes were dug and soil drenching using Monceren T Pencyron + Thiram (4g/1litre) was done. DAP fertilizer at a rate of one teaspoonful per hole was then applied. Immediately after transplanting seedlings, watering around each seedling was carried out. Gapping and replacing was carried out within 14 hrs after transplanting. Wilted seedlings and those cut by cutworms in the evening of transplanting and the following night were replaced the next morning. This was done to ensure all the transplanted seedlings were similar.

3.2.2.3 Kale field management:

After kale seedlings were transplanted a field research assistant was hired to assist in weeding, watering and guarding. First field weeding was carried out three weeks after transplanting and was repeated once every two weeks or as necessary. To ensure plant health and proper growth, Calcium Ammonium Nitrate (CAN) was applied as a top dressing fertilizer, and second application of CAN was repeated four weeks after the first application.

During kale field management, bacterial and viral diseases as well as insect attack on kale plants were closely monitored and data collected during the entire duration of the experiments. All the necessary tools for weeding and spraying were maintained and kept in a guarded field store. The field site was guarded by a hired watchman to prevent intruders from stealing the crop.

3.2.3 Field experimental design

Randomized block design (RBD) was chosen for the experiment. One plot of each treatment was placed in each of the four blocks (Figure1.3). The overall measurement of the experimental site was 22.7m by 17.9m, with a total of 1,152 plants. This trial consisted of 16 plots, each one of 4.8 x 3.6m^2 (Figure 2.3). Each individual plot had 8 rows of 9 plants each. The 2 plants at each end of the rows, and the outer two rows, were designated as guard rows, the net plot consisted of 20 plants. Spacing was 60 cm between rows and 40 cm between plants. The guard of the guard row plants (the most outer row) carried 30 plants in order to avoid spray drift. The guard rows of the net plot carried 22 plants in order to avoid edge effects. Spacing between individual plots was 100cm and 150cm between adjacent blocks.

Two field experiments were carried out. The 1st field experiment started during the short rains of the year 2002, and seeds were sown in the 1st week of September 2002. The experiment was repeated again during the long rains of the year 2003 and seeds were sown in the 1st week of March 2003. Sampling of insect pests, diseases and natural enemies continued for three months for each experiment

Four treatments were randomly distributed in a complete randomized block. Treatments involved spraying with diazinon, marigold juice, chilli juice and leaving a control as follows: Chemical (Diazinon) (T1), Marigold juice (T2), Chilli aqueous extract (T3) and unsprayed control (T4).

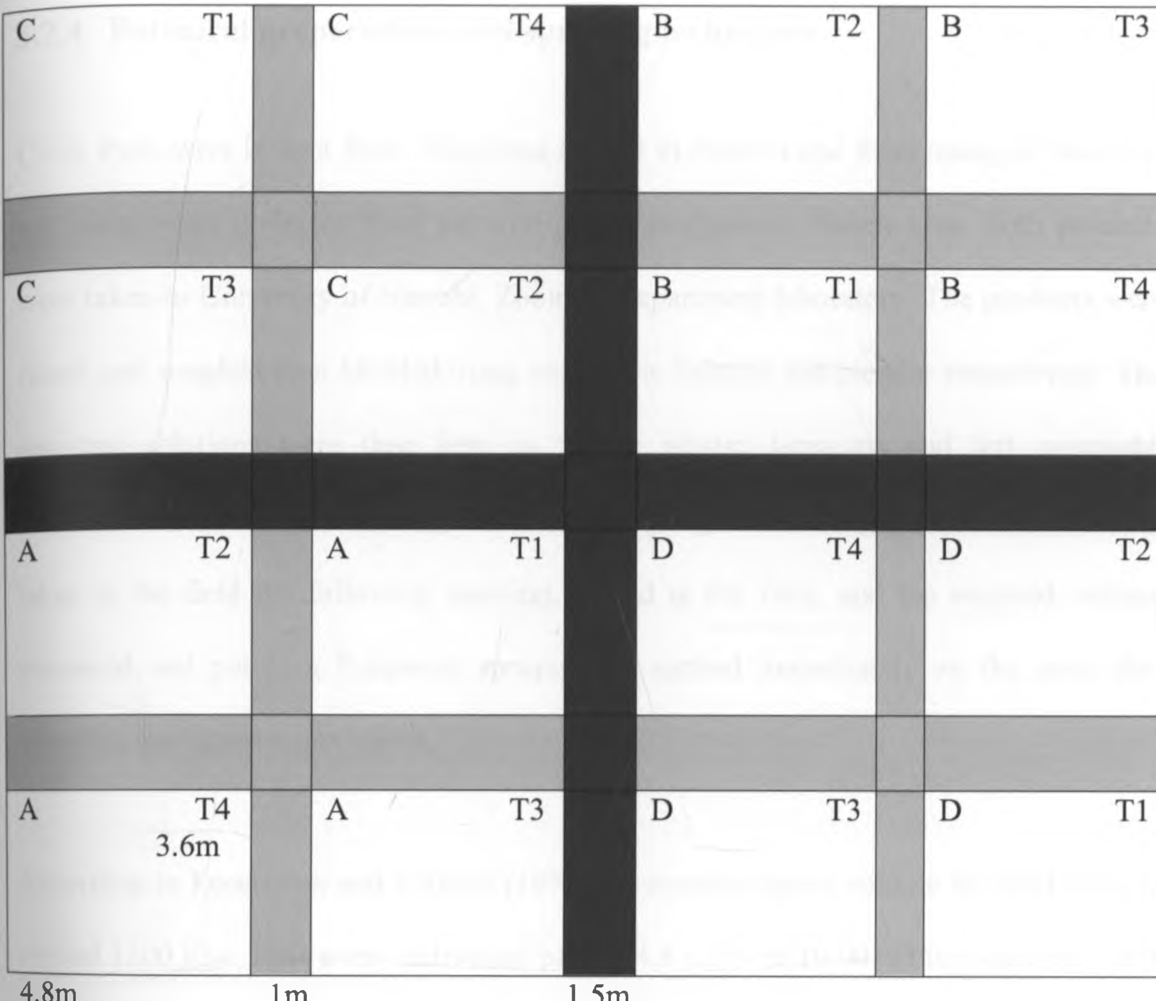


Figure 1.3: Layout of randomized complete block strip trial in a paired treatment experiment protected with the chemical diazinon and aqueous botanical juices of marigold and chilli plants and unprotected plot with four replicates and with guard rows between treatments

Key: *T1= Chemical (Diazinon); T2= Marigold; T3= Chilli; T4= Control (Unsprayed)*

L	L	L	L	L	L	L	L	L
L	G	G	G	G	G	G	G	L
L	G	x	x	x	x	x	G	L
L	G	x	x	x	x	x	G	L
L	G	x	x	x	x	x	G	L
L	G	x	x	x	x	x	G	L
L	G	G	G	G	G	G	G	L
L	L	L	L	L	L	L	L	L

Figure 2.3: Guard rows and net plot in an Individual experimental plot:

Key: *L = Guard of the guard row plants; G = Guard row plants; x = Sampling plants*

3.2.4 Botanical preparations and spraying techniques

Chilli fruits were bought from Wakulima market in Nairobi and fresh marigold branches and leaves were collected from the wild grown marigold at Kabete area. Both products were taken to University of Nairobi, Zoology Department laboratory. The products were rinsed and weighed then blended using an electric balance and blender respectively. The resulting solutions were then kept in 5 litre plastic Jerrycans and left overnight. Concentration of chilli was 300g/l and that of marigold was50 g/l. The solutions were taken to the field the following morning, sieved in the field, and the required volume measured and put in a Knapsack sprayer and applied immediately on the crop after sampling the experimental plots.

According to Fenermore and Prakesh (1992) the standard spray volume for field crops is around 1200 l/ha. Thus every individual plot of 4.8 x 3.6 m^2 (0.00173 ha) required 2.076 l spray volume. During the spraying wind direction was taken into consideration in order to avoid spray drift. Adequate spray coverage of plants was ensured.

3.2.5 Sampling procedures and pest monitoring

Sampling was carried out on a weekly basis, 10 plants out of the 20 in each net plot were randomly sampled. The sampled plants were checked all over for DBM and the number of larvae and pupae was counted and recorded. For sampling aphids, scoring was carried out for one mature selected leaf. The selected leaf for aphid scoring was always the third leave counting from the mature top leaves downwards. For the diseases, a mature leaf was also selected and the percentage of leaf infestation was estimated.

Several studies report that aphids prefer plant material near the shoots (Malais and Ravensberg 1992). Stoyenoff (2001) noted that aphids aggregate on flower buds and young shoots. Thus, this study used one mature leaf on the upper part of the plant as the sample unit for aphids.

Sampling continued for 11 weeks for the first field experiment and 12 weeks for the second field experiment. As well as DBM and aphids, other chewing and sucking insect pests including Plusia (*Plusia* spp), Bollworm (*Helicoverpa armigera*), Cabbage Sawfly (*Athalia* spp), Cabbage web-worm (*Hellula undalis*), Flea beetle (*Phyllotreta* spp), Bagrada Bug (*Bagrada hilaris*), Whiteflies (*Bemisia tabaci*) and Thrips (*Thrips* spp.) were scored and recorded. For the diseases since they also reduce yield, virus, bacterial blackrot, Yellows, Cottony rot and Powdery mildew were recorded. Natural enemies found from the whole plant recorded during field experiments were syrphid larvae, spiders, ants and wasps.

Apart from weekly sampling, continuous field monitoring was carried out and physical factors such as rainfall and weather changes that could influence insect pest presence or absence, as well as disease occurrence were recorded. Meteorological data was also received from the meteorological department that maintains records for the same field research farm of Kabete.

3.2.6 Harvesting and yield assessment

Harvesting started four weeks after transplanting and continued for eight weeks. All mature leaves were harvested once every two weeks. Leaves from each individual plot were harvested separately and weighed. Marketable (leaves which were free from insect and diseases infestations) and unmarketable (infested by insect pests and diseases) leaves were counted and weighed. Data was recorded in a prepared field data sheet. After data collection, the harvested leaves were given to the casual labours that helped in harvesting, and weeding the experiment. DBM and aphid damaged leaves could easily be recognized by their specific and notable damages they make. The cause of damage on unmarketable leaves was therefore assessed and designated as insect damage, and /or disease.

3.2.7 Data analysis

Data from the field trial was entered in an Excel spreadsheet and the data for DBM, aphids, diseases and natural enemies were then summarized. A statistical package that is designed to analyze scientific research findings "GenStat" 7th edition was used to analyze the data to investigate differences between treatments.

During this field experiment, insect abundance and disease incidence were very low, and data from the 1st week of sampling to the 8th week was not significant for analysis. Therefore, the data analysis started from week nine to week eleven. Analysis of variance (ANOVA) was carried out on DBM, aphids, disease and the natural enemies which were present in the experimental plots and means of treatments were compared.

The repeat of 2002 second field experiment, analysis of residuals revealed that the data did not meet the parametric analysis of variance assumption of normality, and population variances appeared to be heterogeneous. In addition to assume the normality of the data, the data was transformed to logarithm due to some observed values that showed zero (0) and yet the residual test displayed nonhomoscedastic type of residual graphs. Therefore, as Zar (1996) explains, Kruskal-Walis-One-way ANOVA test was used to analyze the data.

For yield data analysis, the preliminary and residual test showed that the observed variables are approximately normally distributed, therefore two-way analysis of variance (ANOVA) was carried out for exploring the difference between treatments.

3.3 RESULTS

3.3.1 Insect pests, diseases and natural enemies field occurrence results

Analysis of average DBM and aphid score during the short rains season of 2002 was conducted from week nine to week 11, as from week one to week eight shows that there were very few insects present. The analysis of week nine showed no significant difference between the treatments ($P>0.05$). However, comparison of similar analysis in week 10 and week 11 reveal a significant difference between treatments ($P<0.05$) (Figure 3.3).

The treatment means showed that unsprayed plots had the highest mean while chemical sprayed plots showed the lowest mean number of DBM larvae. In the 2nd field experiment (2003 long rains), the non-parametric test results showed that the DBM larvae and *B. brassicae* presence was highly significantly different between the treatments ($P<0.001$). Virus occurrence was not significantly different between treatments ($P>0.53$). For natural enemies, the presence of syrphid larvae was not significantly different between the treatments ($P>0.75$) while the presence of spiders was ($P<0.05$).

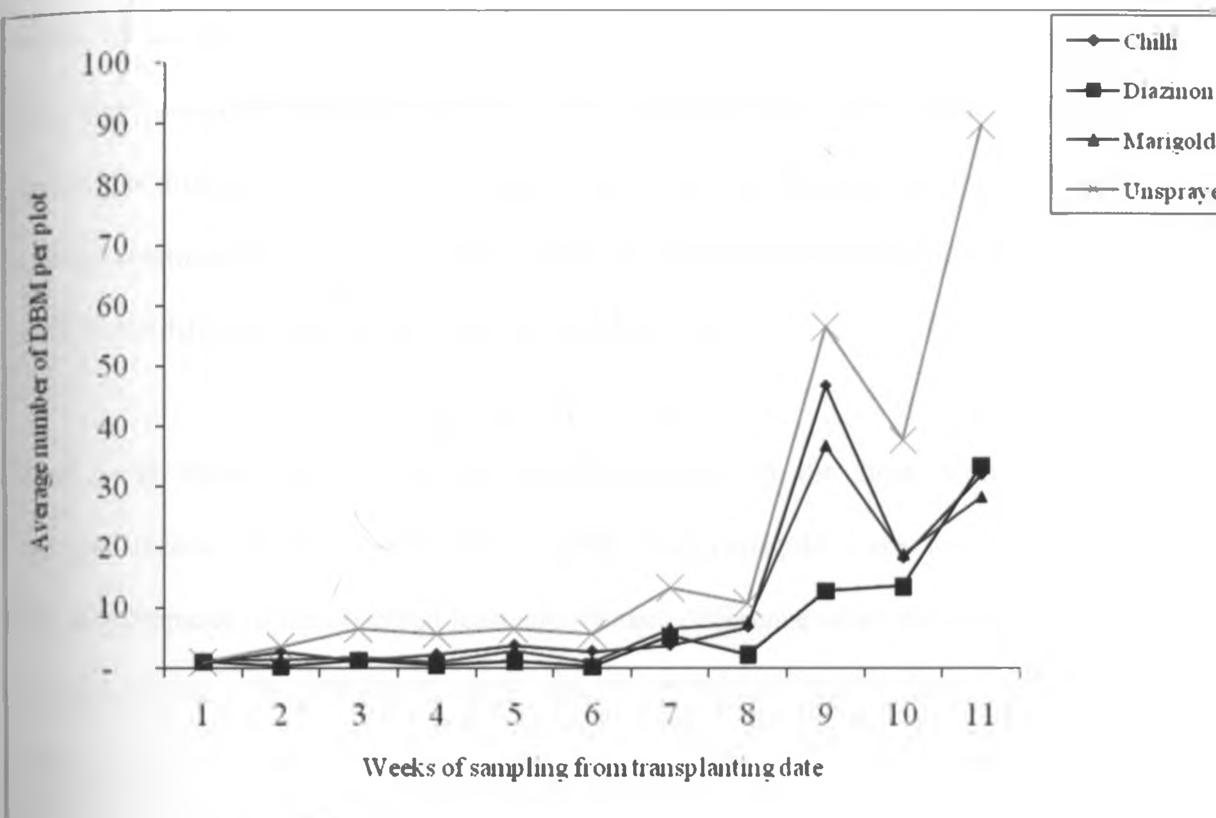


Figure 3.3: Average number of DBM larvae present per plot per treatment (2002 field experiment). (Number of DBM in different treatments by different weeks of sampling from the transplanting date showing the highest number of DBM at control treatment, while the lowest number of DBM were present in chemical sprayed plots)

DBM larval field infestation was very minimal for the first eight weeks (Figure 3.3) although control plots showed the highest average of DBM infestation. At the last two weeks for sampling, botanical and chemical sprayed plots showed almost the same number of DBM larvae while DBM incidence shot up in the control plots. Chemical, chilli and marigold treatment means were compared with each other using least significance difference (l.s.d = 5.284) and it was found that chemical treatment and both botanical treatment levels were not scientifically different while the control treatment was significantly different from all the other three treatments.

Figure (3.4) shows *Brevicoryne brassicae* infestation in the field. Comparison of treatment means showed that chemical, chilli and marigold were not significantly different compared to the observed least significance difference of all the treatments (l.s.d = 0.0906) but the control treatment means were significantly different from the rest of the treatments.

The result obtained during the 2003 long rains field experiment showed that DBM larval intensity and the presence of aphids were higher than that obtained the 2002 field experiment.

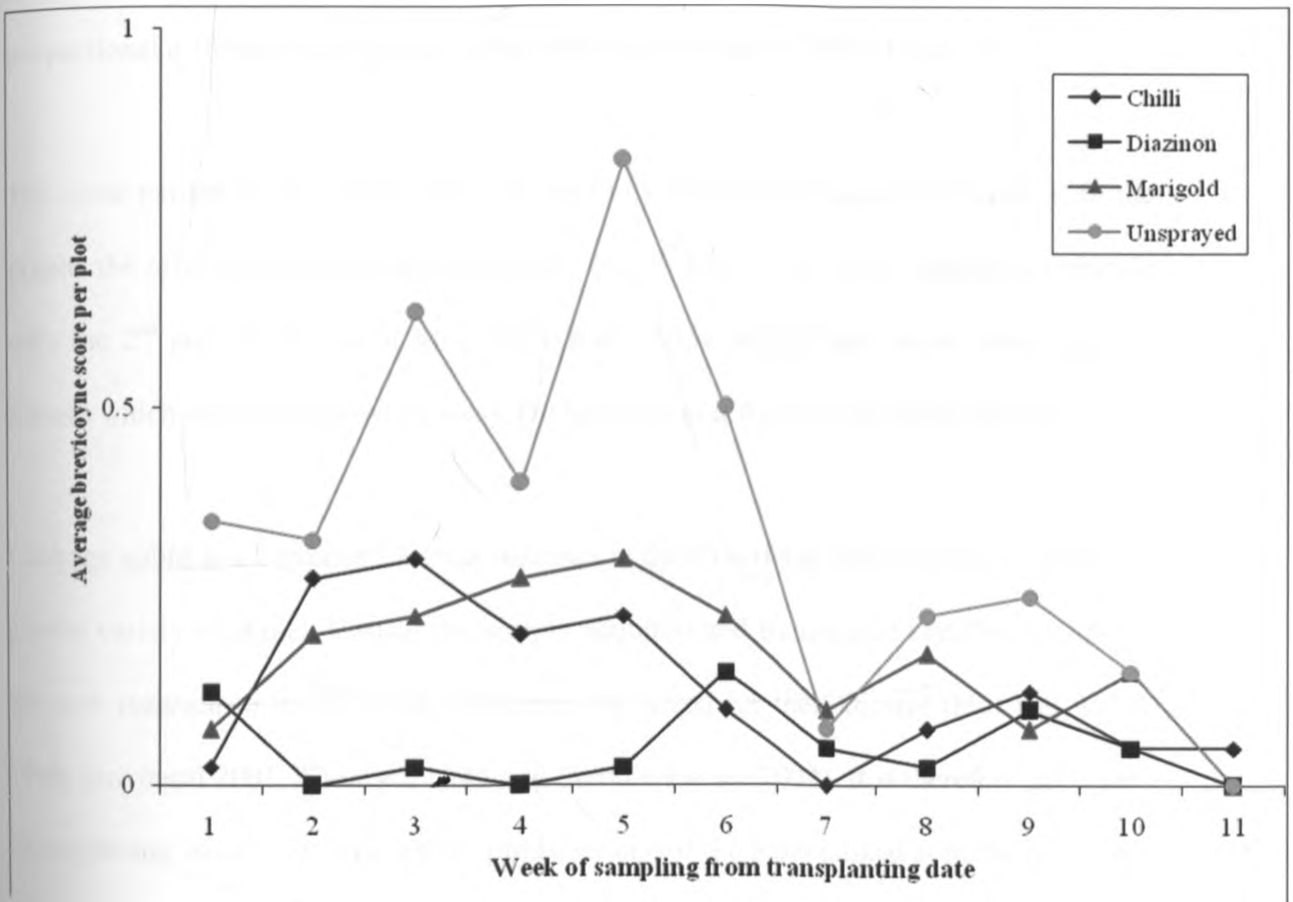


Figure 3.4: Average *Brevicoryne* per plot per treatment (2002 field experiment). (Score of *Brevicoryne* in different treatments by different weeks of sampling from the transplanting date showing the highest number of *Brevicoryne* at control treatment, while the lowest number of *Brevicoryne* were present in diazinon sprayed plots)

DBM populations in the botanicals and chemical treated plots showed a similar pattern, i.e. the treatments mean were lower than those in the unsprayed control. In this case, it appears that the botanicals had a similar effect as the diazinon. In both seasons (2002 and 2003) the highest DBM populations were in the control treatment, although the proportional difference was greater in the 2003 season than in 2002 (Figure 3.5).

The same pattern is also visible from figure (3.6) which shows aphid population. In the graphs the effect of rainfall was noticeable. The 3rd and 4th weeks of sampling coincide with the 2nd and 3rd Weeks of May 2003, and in this period there were heavy rains in Kabete which could have washed away DBM larvae and *Brevicoryne* nymphs and eggs.

Cabbage aphid is a vector of 23 virus diseases in the Cruciferae and is a common pest on a wide variety of plants. Viruses are simply acquired and transmitted rapidly, but aphids are now resistant to many of the chemicals registered for their control (Hill and waller 1990, Stoyenoff 2001, Thomson 1994 and Summers *et al.* 2004). It is therefore necessary to sample the virus infestation when aphids are one of the pests looked at in the research.

The diagram (Figure 7.3) shows cauliflower mosaic virus infestation in the 2003 long rains experiment. The first four weeks virus infestation was almost non-existent, but started infesting plants gradually until its score almost reached five (the highest score given in this experiment which means all the leaf was covered).

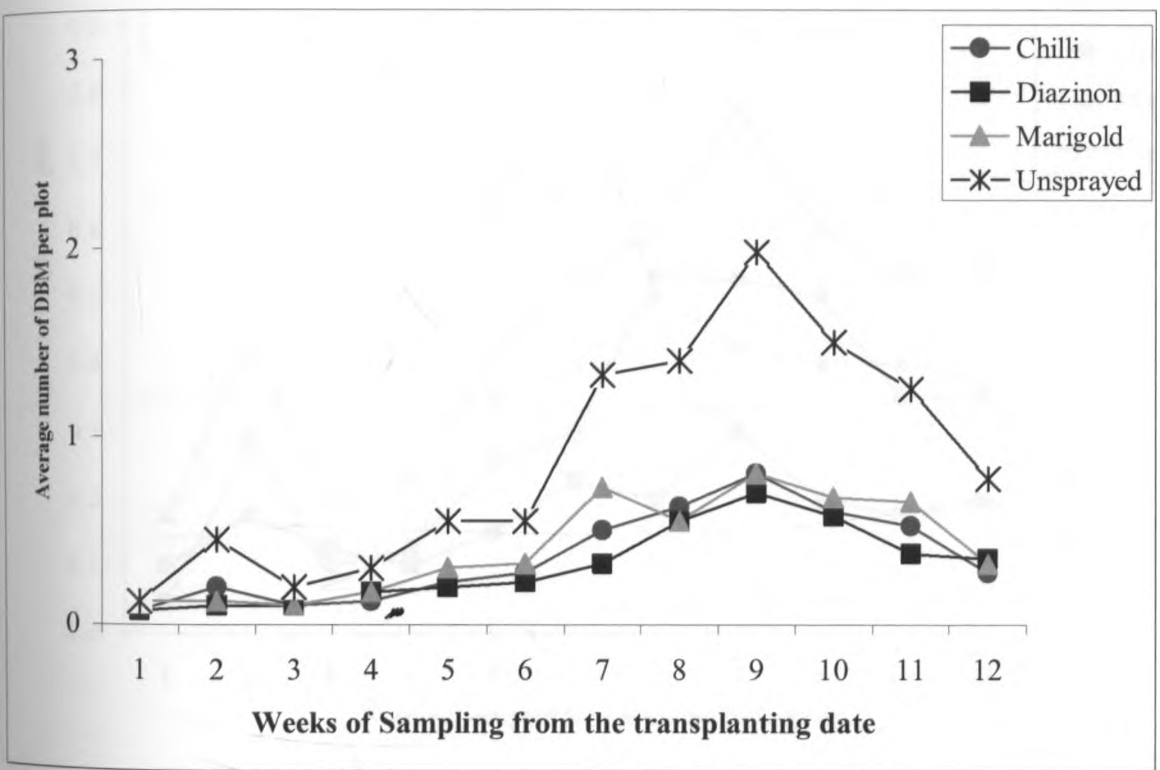


Figure 3.5: Average number of DBM larvae per plot (2003 field experiment). Unsprayed plot show the highest number of diamondback moth while other three treatments (diazinon, chilli and marigold) almost show the same pattern of DBM occurrences in the plots

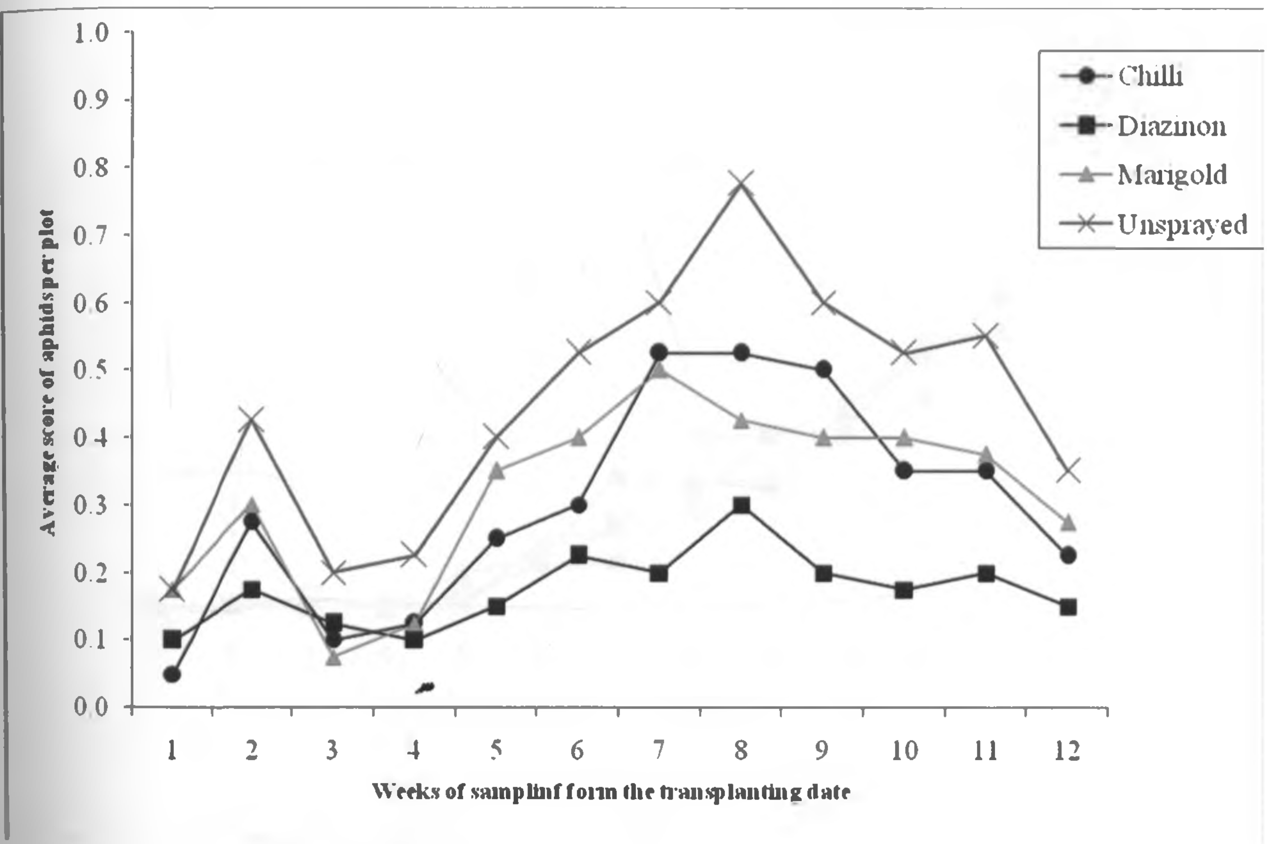


Figure 3.6: Average score of *Brevicoryne* per plot per treatment (2003 field experiment). Unsprayed plots show the highest number of aphids while chemical sprayed plots show the least aphid presence. Botanical (chilli and Marigold) sprayed plots show similar results of aphid presnece

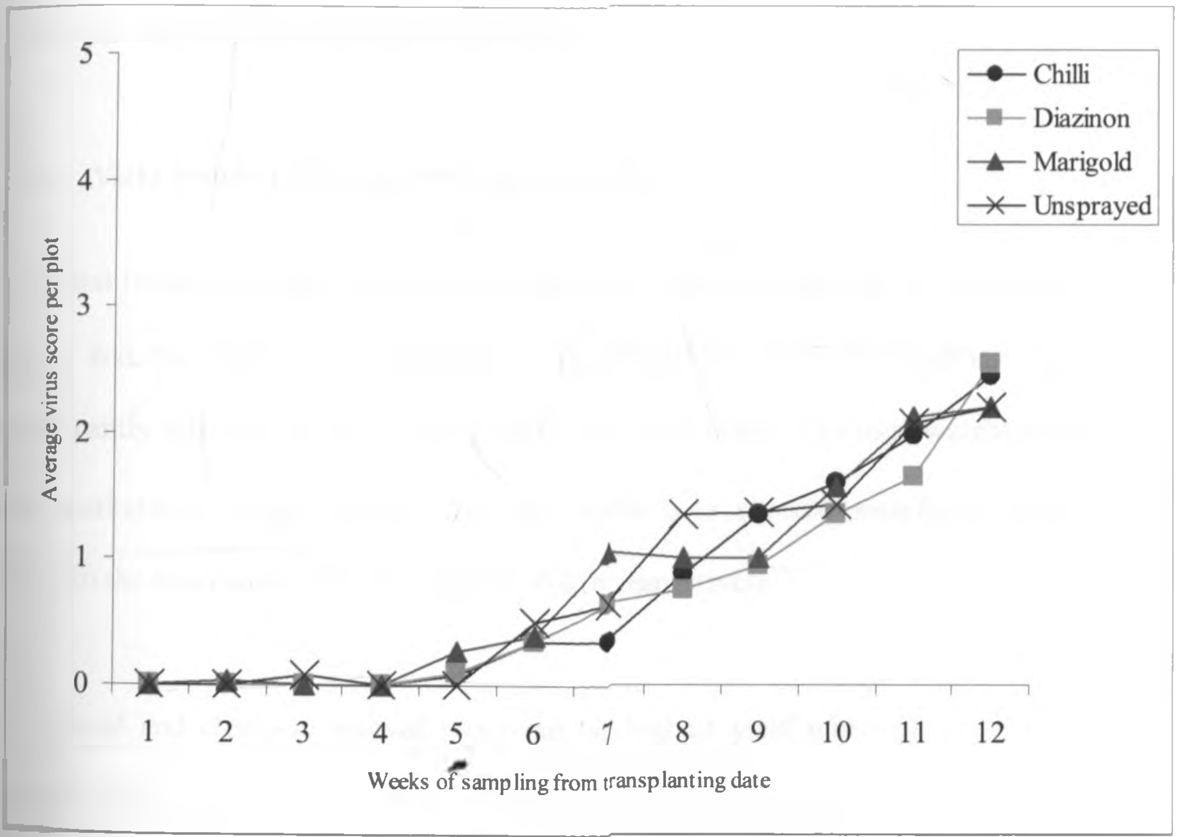


Figure 3.7: Virus score per plot per treatment (2nd replicate of 1st field experiment). Virus infestation reached its highest score of 5 but the graph presents average score per plot per treatment)

The presence of spiders in the chilli sprayed plots was not different from the chemical sprayed plots, and the mean of the marigold sprayed plots is not significantly different from the mean of the unsprayed plots. However, the chilli sprayed plots was different from that of the marigold and the unsprayed plots. In addition, the presence of syrphid larvae the means of all treatments were similar.

3.3.2 Yield results (2002 and 2003 experiments)

The total marketable and unmarketable number of leaves as well as the total weight of leaves and the total yield (marketable + unmarketable) of all the treatments are not significantly different (P>0.05) in the 2002 field experiment. The total weight of leaves and marketable weight (Figure 3.13 and Table 3.1) showed significant difference between the treatments (P<0.001) and (P=0.016) respectively.

Unsprayed and chemical sprayed plots had the highest yield while plots sprayed with marigold had the least yield. All treatment means were not significantly different except for the plots sprayed with marigold which was significantly difference from other treatments when analyzed total weight and marketable weight of leaves (Fig. 3.8).

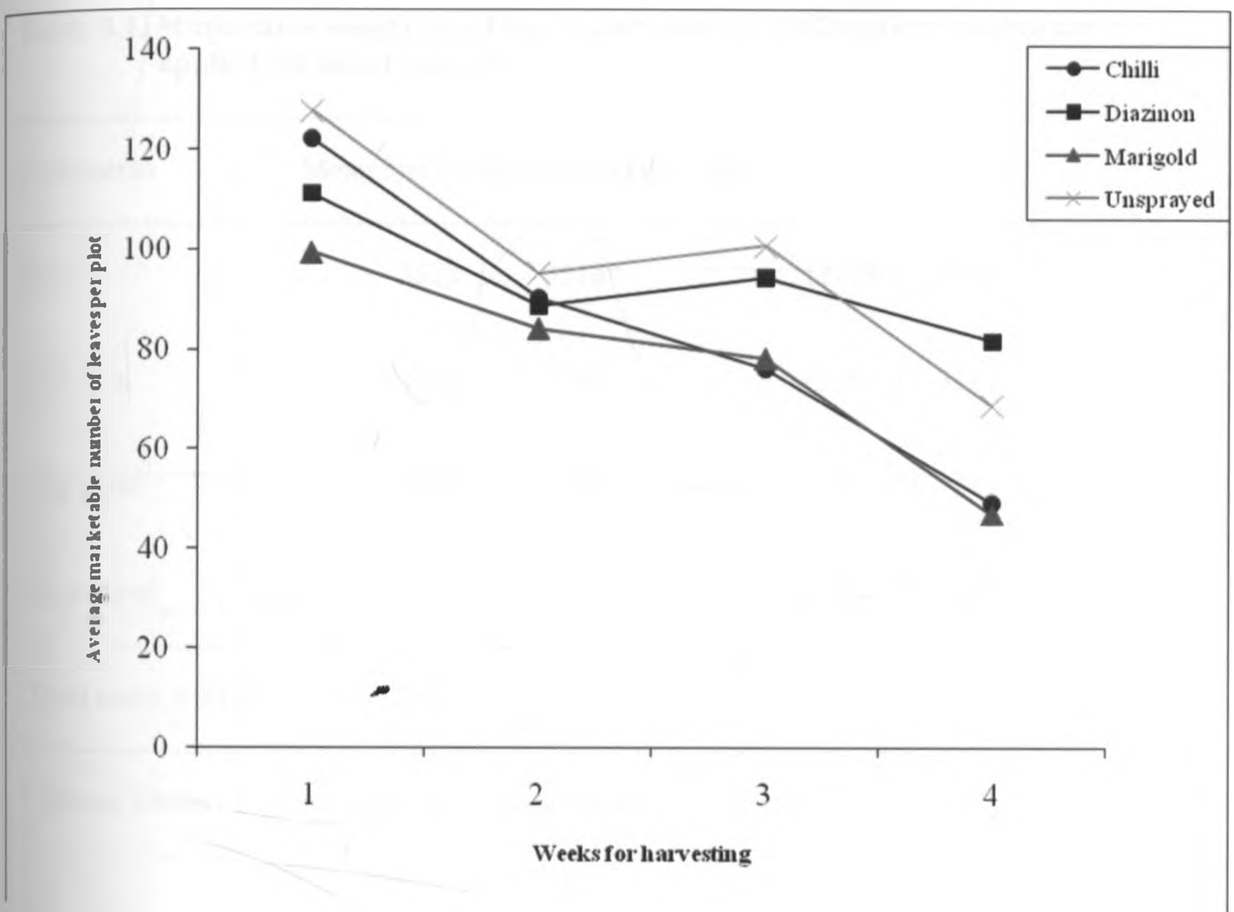


Figure 3.8: Average number of marketable leaves per plot per treatment (2002 experiment)

Table 3.1. Marketable weight (g) of leaves harvested in 2002 against treatments applied for insect control

Treatments	Mean marketable weight (gr) ± SE	95% (CI)
Chilli	2522 ± 351a*	(1774.37, 3269.63)
Diazinon	2700 ± 229a	(2212.23, 3187.77)
Marigold	2150 ± 329b	(1449.23, 2580.77)
Unsprayed	3119 ± 361a	(2430.07, 3887.93)
Total mean ± SED	2623 ± 208.3	(2206.82, 3039.18)

* Means labeled the same letter are not significantly different

In 2003 long rains field experiment, the two-way ANOVA showed that the overall number of marketable leaves were significantly different between treatments (P<0.003). Comparison of individual treatment means showed that the mean number of marketable leaves of each treatment was different from the rest except for the chilli and marigold treatments which were not significantly different. Marketable weight was also significantly different between the treatments (P<0.001) as well as the unmarketable number and the weight of leaves (P<0.001). The total weight of yields was significantly different (P<0.001), but on the contrary the total number of leaves was not significantly different between all the treatments (P=0.428). The two-way ANOVA was used because it has been noticed that weeks of harvesting were also significantly different between treatments (P<0.001). Table 3.2 shows the means of all treatments according to the weeks of harvesting.

Table (3.3) indicates that the means of the chemical sprayed plots and the chilli sprayed plots are not significantly different. Unsprayed plots and the marigold sprayed plots have the same mean number of unmarketable yields but significantly more than in the chilli and diazinon treatments.

Table 3.2 Mean number of marketable leaves per treatment per week

Treatments	**Weeks**			
	1	2	3	4
Chilli	112	121	104	60
Diazinon	111	135	94	59
Marigold	82	90	101	59
Unsprayed	98	117	85	61

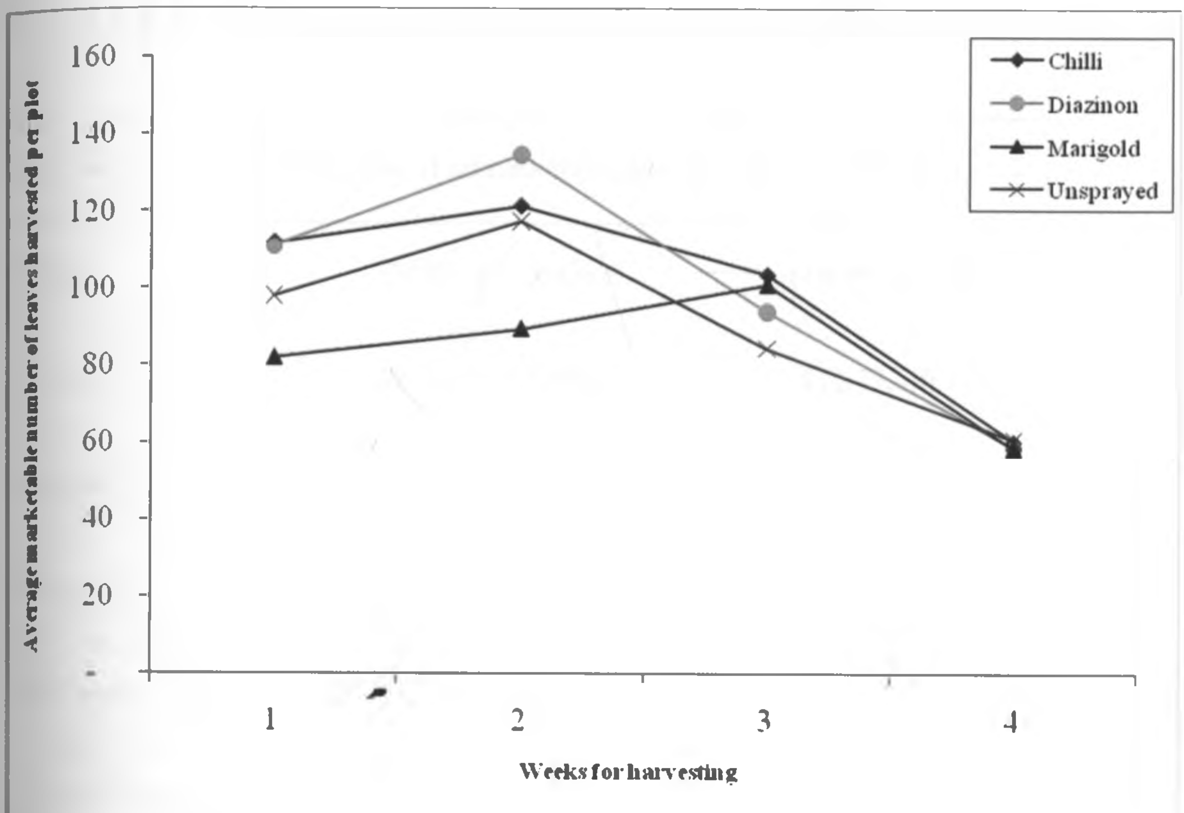


Figure 3.9: Average marketable number of leaves per plot per treatment (2003 experiment)

Table 3.3: Unmarketable mean number of leaves harvested per treatment per weak

Treatments	Mean no. of unmarketable leaves ± SE	95% (CI)
Chilli	26.88 ± 5.83a	(14.46, 39.30)
Diazinon	28.25 ± 5.88a	(15.73, 40.77)
Marigold	44.50 ± 8.67b	(26.03, 62.97)
Unsprayed	44.00 ± 7.40b	(28.24, 59.76)
Total mean ± SED	35.90 ± 2.63	(30.65, 41.16)

* Means labeled the same letter in the same column are not significantly different from each other, P<0.05.

The two graphs below (Fig. 3.10 & 3.11) show marketable and unmarketable weight of yield in the 2003 experiment. Fig. 3.10 shows that the yield from the marigold and unsprayed plots exhibited the lowest weight while figure 3.11 shows that the marigold sprayed plots had the highest weight of unmarketable yield. During all the field experiments of the 2002/2003 plants from the marigold sprayed plots showed some irregularities, and it is possible that crude marigold concoction had some negative effects on plants and caused leaf scorching. The preliminary assumption here is that marigold tea at the concentration of 50g/l might be phytotoxic to the kale plants (Plate 4.3).

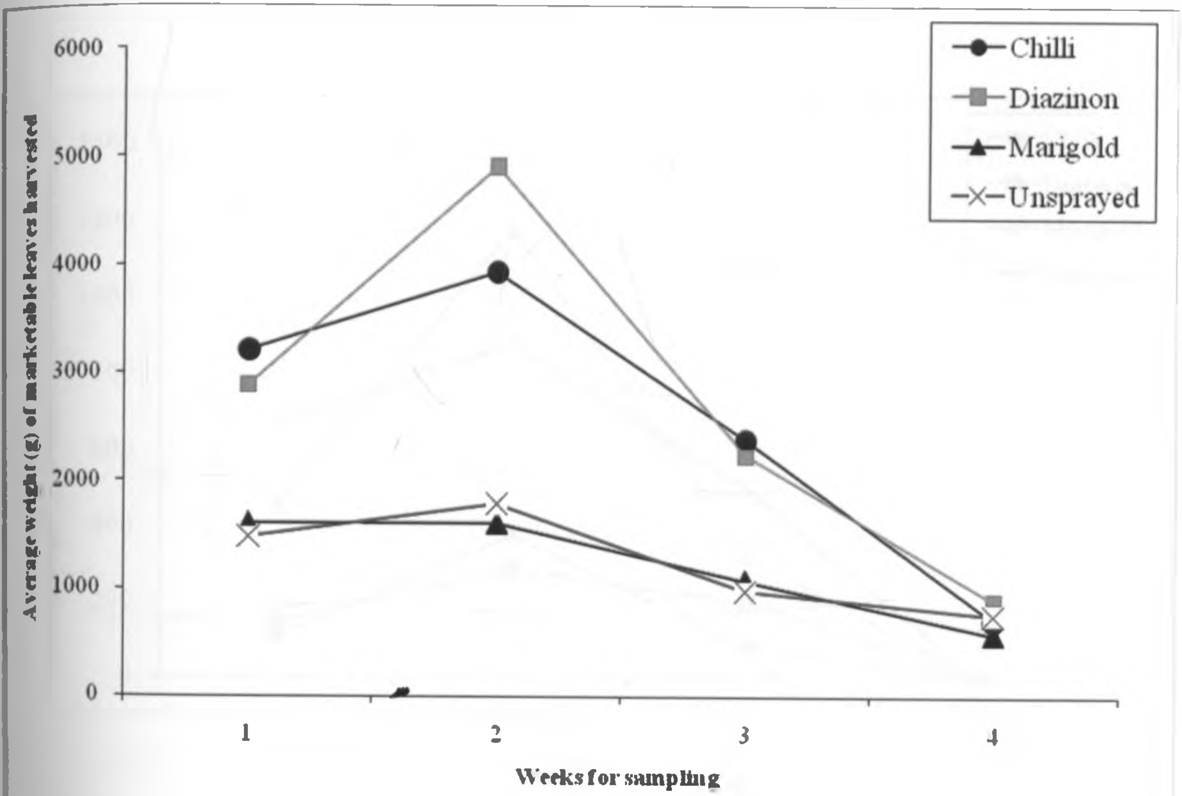


Figure 3.10: Average marketable weight (g) of leaves per plot per treatment (2003 experiment)

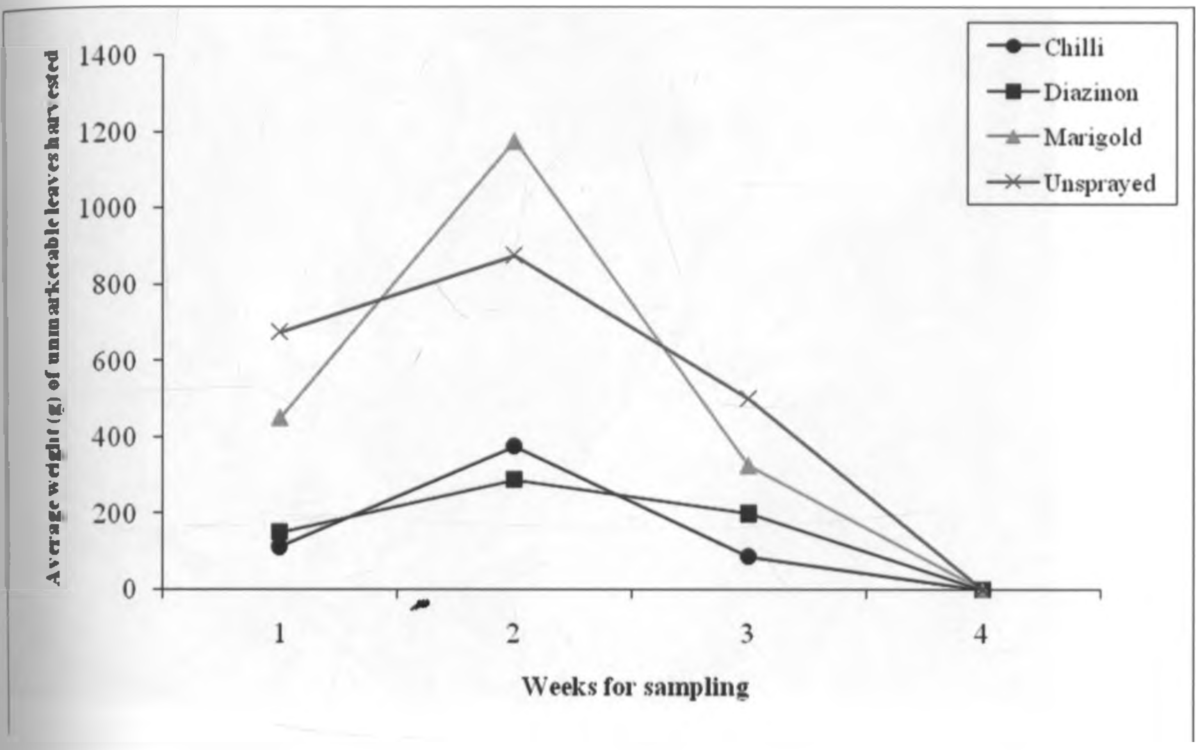


Figure 3.11: Average unmarketable weight (g) of leaves per plot per treatment (2003 experiment)

Plate 4.3: Marigold sprayed plant showing leaf burning and reduced size. (There is a possibility that these leaves burnt and scorched due to phytotoxicity of Marigold)

The total number of leaves (Figure 3.12) indicates an important result, that all the plots produced the same number of leaves. The effects of different treatments are not visible in the total harvest. The different treatments played an important role in the marketability and un-marketability of the yield. On the other hand, the total weight of the yield is significantly different (Figure 3.13) and here, the observation is that the damage by both chewing and sucking insects as well as diseases infestation reduced leaf size and growth regularity of the plants which led to reduction in yield.

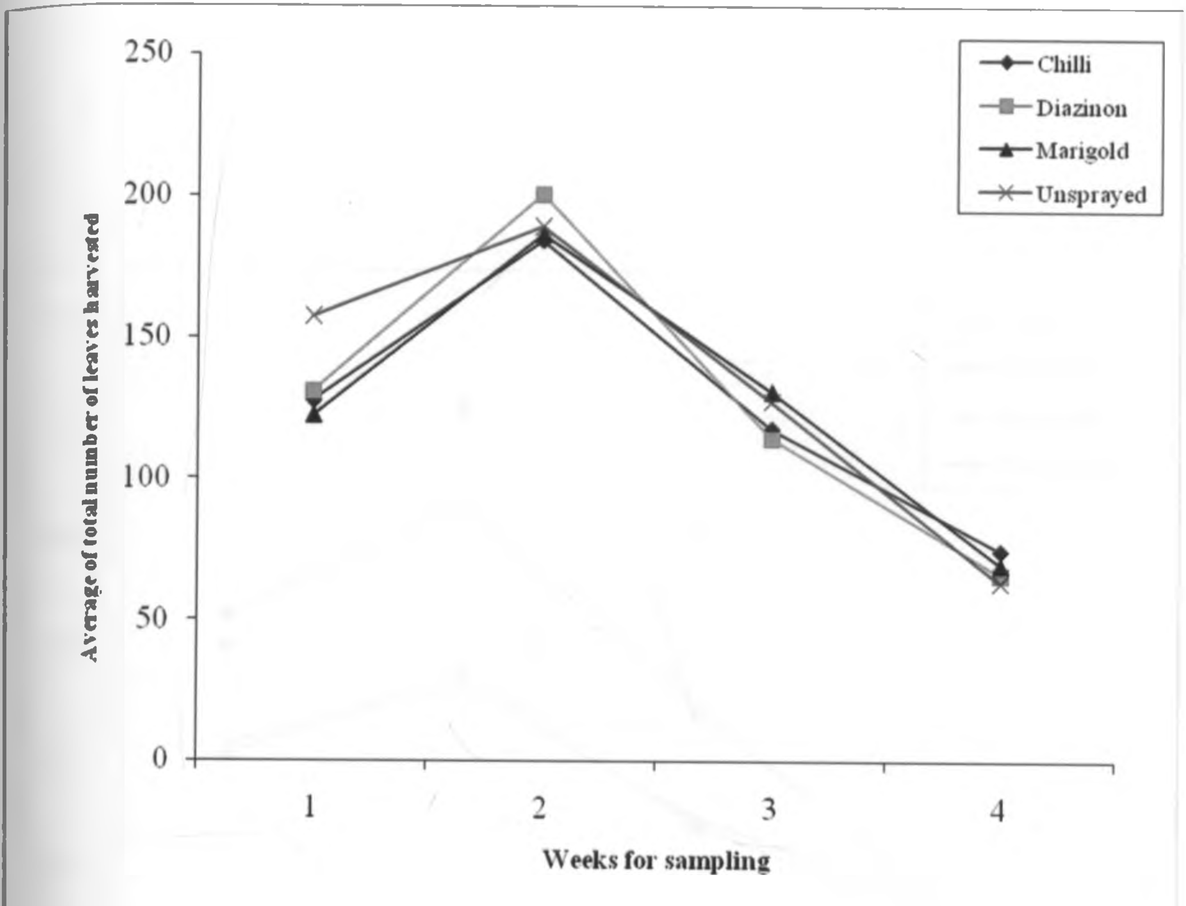


Figure 3.12: Total average number of leaves harvested per treatment per plot

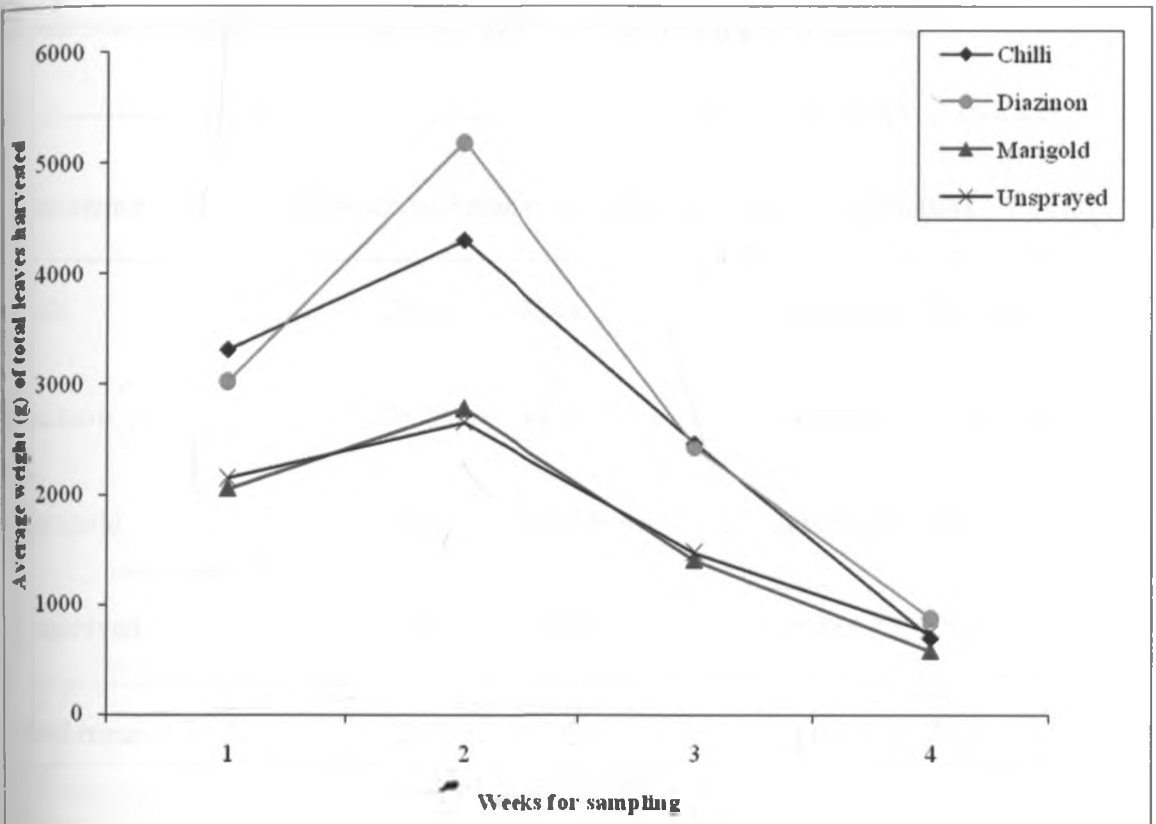


Figure 3.13: Average total weight (g) of leaves harvested per treatments per plot

Table 3.4. Mean of total weight (g) of leaves harvested per treatment

Treatments	Mean unmarketable no. of leaves ± SE	95% (CI)
Chilli	2694 ± 384a	(1876.08, 3511.92)
Diazinon	2878 ± 417a	(1989.79, 3766.21)
Marigold	1700 ± 256.9b	(1152.80, 2247.20)
Unsprayed	1757.5 ± 235.8b	(1255.25, 2259.75)
Total mean ± SED	2257 ± 165.0	(1905.55, 2608.45)

* Means labeled with the same latter in the same column are not significantly different from each other, P<0.05.

3.4 DISCUSSION

Insect population in both 2002 and 2003 field experiment was low, although the 2003 results showed that there was a higher number of insect pest population than it was in 2002. DBM larval and aphid intensity in the plots sprayed with chilli and marigold were similar to those of the chemical sprayed plots. The results obtained in this study reveal that the diazinon treatment cannot perform better than the chilli and marigold treatments in the reduction of insect pest populations and in increasing yields.

Chilli and marigold can act as good as diazinon in controlling insect pests because both the 2002 and 2003 field experiment observations revealed that 44.11% and 44.54% of the total larvae counted were found in the unsprayed plots respectively. The percentage of larval count in the chilli and marigold plots was 22.57% and 20.01% respectively for the first field experiment. The chemical sprayed plots had 13.31% of the total larvae counted in the 2002 experiment. Low larvae and aphid population reduction in the plots sprayed with chilli and marigold can explain the repellency and antifeedant capacity of both botanical products.

Parmer (1993) explained that botanical extracts are non- toxic to natural enemies if used at lower concentrations. As such since the concentrations used in these experiments were high, it is also expected to do some harm to the predators. Physical factors also affected the mean percentage of DBM larvae and aphid infestations on the plants. Analysis showed Weeks were significantly different ($P<0.001$), therefore rainfall and climatic conditions might have affected insect populations.

Although yield results of the two experiments varied, the chilli and chemical sprayed plots always showed the highest yield except in the first field experiment in which unsprayed plots also had high yield. Yield from the marigold sprayed plots revealed non-contradicting results and kept producing the least yield from all the treatments. In this regard, there is a suggestion that marigold may contain some growth inhibitory materials. In addition, there may be a phytotoxicity problem with marigold application; leaf burning and necrotic spots formed on almost all the leaves of marigold treated plants. In the past some studies such as Zhang *et al.* (2004) had established the problem of phytotoxicity when ginger oil was applied on tomato seedlings where the plant suffered with necrotic spots.

Generally, it is believed that botanical insecticides are environmentally non-persistent and do not damage crops, but some studies argue that botanicals can have negative impact on non-target organisms such as natural enemies, and can pose a risk to human health (Isman 1997).

Non-purified crude plant extracts always contain a complex mixture and elements with active compounds. These compounds may exhibit superior bioactivity than one single chemical insecticide (Leatemia and Isman 2004). Due to their constituents, crude extracts may have side effects on the crop similar to the ones which were shown by marigold. However, the quick biodegradability of plant materials, their repellency and antifeedant effects can enhance their role in the insect pest control.

Data on natural enemies was very limited, yet it was observed that chilli treatment had some effects on the natural enemies particularly spiders; but this still requires more specific studies. Nevertheless, the available literatures on botanical pesticide show different results on the toxicity of crude aqueous extracts to natural enemies. Some researchers have reported that the toxicity and knock down capacity of botanicals are minimal, while some others believe that botanicals can have negative impacts on the non-target organisms (Leatamia and Isman ,2004, Isman, 1997).

2002 and 2003 field experiments showed different results of insect pest infestations and yield. The 2002 and 2003 short and long rains seasons rainfall was low and both seasons were dry. In 2002 the sampling were conducted in October, November and December and the total rainfall of these months at Kabete were 59.1mm, 157.2mm and 230.9mm respectively; while the sampling months of 2003 were April, May and June and the total rainfall of these months were 146.2mm, 108.1mm 1nd 30.2mm respectively. Due to these reasons the number of insects was low. Consequently, the expected yield resulting from damage caused on leaves and efficacy of the treatments may have been affected.

Lale (1992) reported that the advantage of using chilli products is its availability locally and that it can easily be afforded by peasant farmers. The result obtained in the present study is in agreement with what has been reported because farmers during the indigenous farmers knowledge in this study expressed similar reasons. Chilli as aqueous extract can be used as a field spray to repel insect pests.

In conclusion, the results obtained in this study have strong argument that botanicals particularly chilli and marigold repelled the insects or caused feeding deterrence or even could have some type of knock-down capacity. Chilli and marigold product formulations need to be improved, reduction of phytotoxicity and residual time as well as application time to be examined and enhanced.

CHAPTER FOUR

4.0 EVALUATION OF REDUCED FREQUENCY USE OF CHEMICAL INSECTICIDE ON DIAMONDBACK MOTH AND CABBAGE APHIDS IN KALE FIELD

4.1 INTRODUCTION

Reduced frequency of chemical pesticides applications could result into reduced productivity of a crop. However, if the level of pesticide reduction is known, crop production could be enhanced through integrated methods by adding botanical pesticides in the treatment regime.

The use of bacterial and botanical formulation as pesticides could reduce synthetic insecticide applications. This would be advantageous to the environment and minimizing poisoning in agricultural production as well as increasing farm inputs. Use of botanical insecticides with reduced frequency use of chemical insecticides could possibly reduce selection pressure and improve insecticide management.

Traditional or cultural insect pest control methods such as crop rotation, pruning etc provide opportunities to establish integrated pest management programmmes between extension and institutional research with indigenous farmers. Technology developed together with peasant farmers can be also easily transferred to the end users.

The need for new techniques to replace the most persistent pesticides has resulted in an increase of alternative synthetic pesticide research and many field and laboratory demonstrations and trials (Brewer *et al.* 2004). Such projects and the present study are aimed at discovering and developing reduced-risk pesticides and alternatives to pesticides in pest control strategies.

Fuester *et al.* (2004) reported that alternative control method is required to reduce the use of methyl bromide for agricultural commodities. In addition, alternatives are needed and solution may be in the reduction of pesticide load of the environment through their need based, sensible use and rotational application (Parmer, 1993).

Marigold was not used in this experiment due to its negative impact and the observed phytotoxicity problem to the crop in the 2002 and 2003 field experiments. Chilli solutions and diazinon were used in this experiment as alternating treatments. The use of chilli as alternating treatment with chemical insecticides will have two advantages, first is the reduction of cost of chemical farm input and secondly, residual toxicity of the frequency use of chemicals.

Reitz *et al.* (2003) discussed alternative management tactics to control thrips in an open vegetable crop. The study researched plastic soil mulches, use of insecticides and releases of predators could be an effective control measure and reduces the risk of heavily applied synthetic insecticides. The present study also tried and tested chilli as an alternating treatment with Diazinon and reduced frequency application of Diazinon to the field to reduce the risk related to the application frequency and continuous use of chemicals.

Diamondback moth is the most serious and destructive cosmopolitan insect pest of crucifers (Bedenes-Perez *et al.*, 2004). Several studies have suggested alternative management techniques to reduce synthetic insecticide resistance by DBM (Talekar and Shelton 1993, Hooks and Johnson, 2003). Therefore, the focus of this study was to evaluate the effect of reduced frequency chemical insecticide spray and comparisons were made between the weekly sprayed chemical with reduced frequency spray treatments. Data collection continued for 13 weeks during the short rains of 2003 (September-December).

Diamond back moth and cabbage aphids have developed resistance to many insecticides. The present study is therefore, trying to minimise further resistance and aims to introduce the possibility of reducing the frequency use of insecticides.

Efficacy evaluation experiments conducted during the present study in 2002 and 2003 short and long rains respectively indicated that chilli had some potential for controlling insect pests in kale, but was not effective alone. This suggested that it might be possible to use chilli to reduce the frequency of chemical insecticide application. The objective of the field trial reported in this study was to establish the potential for the reduction of the frequency of spraying chemical insecticides against insect pests of brassicas by the combination of some botanical formulations as alternating treatments.

4.2 MATERIALS AND METHODS

4.2.1 Field Experiment

Field experiment was conducted at the University of Nairobi Agricultural Research Station in Kabete. The experimental site as well as materials and methods used for Kale planting and seed sowing, transplanting, kale field management, sampling procedures and pest monitoring, chilli preparation, and spraying techniques, harvesting and yield assessment have been described in chapter three and remain the same as in the first field experiment conducted during the short rains of 2002 and repeated during the long rains of 2003 (Chapter three of this thesis). However, the block sizes and treatments used were entirely different from the previous experiments.

Kale seedlings were transplanted to a prepared site of 25m x 21.4m including a 1.5 buffer between treatment blocks and a 1m gap between treatment plots (Figure 1.4). The experimental design used was randomized complete block design. There were four blocks with six treatment plots per block at a size of 4.8 x 3.6m^2 each (Figure 2.4). Each individual plot had 72 plants. Spacing between plants and rows was as in the 2002 and long rains of 2003 field experiments.

Diazinon 30EC of Oral LD_{50} 4167 and chilli concentration of 300g/l was sprayed in the field. However, the weekly use of diazinon was reduced for biweekly and once in every three weeks. Efficacy of both diazinon and chilli were also evaluated as alternating treatments. The application method of the treatments were: Weekly diazinon (T1), one week diazinon alternated by two weeks chilli (T2), one week diazinon one week chilli (T3), Diazinon sprayed once in every two weeks (T4), Diazinon sprayed once in every three weeks (T5) and no spray (T6). The selection of the treatments were intended to explore a more suitable and environmentally acceptable approach for the management and control of two of the most insecticide resistant insect pests i.e. DBM and cabbage aphids.

Immediately after transplanting seedlings to the prepared site, the following night Cutworms (*Agrotis* spp) emerged and damaged several transplanted seedlings. They entirely cut some plants and in others partly cut the plant stems so wilting was noticed in the following morning. Near the seedlings which had been cut, a small hole was dug and larvae which were found were removed. The same evening Karate (*Lambdacyhalothrin*) was sprayed on the soil and nearby each seedling to control further damage.

Cutworm is a polyphagous nocturnal lava attacking and damaging seedlings of most crops including crucifers. Older caterpillars feed at night and cut roots and stems of young plants, and a single cutworm larva can destroy a large number of seedlings (Hill and Waller, 1990).

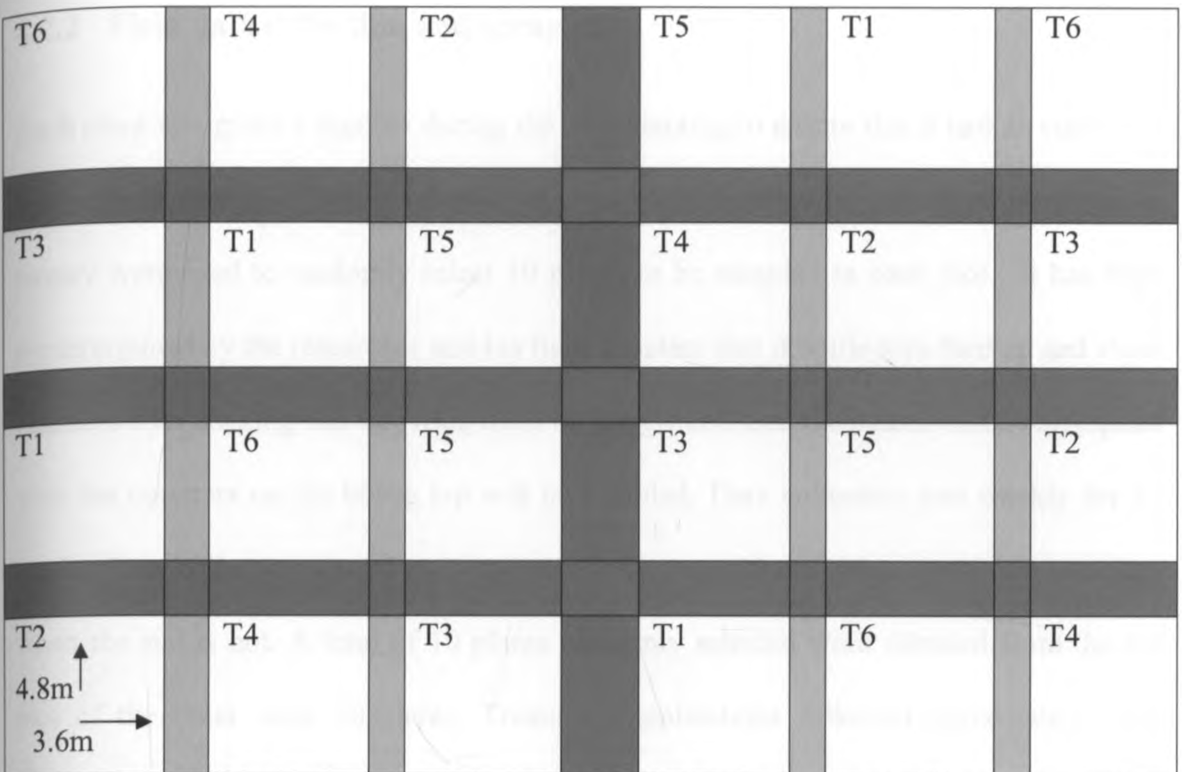


Figure 4.1: 2nd phase Field experimental plot design. Layout of randomized complete block strip trial in a paired treatment experiment protected with the chemical diazinon and aqueous botanical juices of chilli plants and unprotected plot with four replicates and with guard rows between treatments

T1=Weekly Diazinon) **T2**= 1 week diazinon and 2 weeks chilli

T3= 1 week diazinon and one week chilli **T4**= bi-weekly diazinon

T5= diazinon once every 3 weeks **T6**= Control (no spray).

L	L	L	L	L	L	L	L	L
L	G	G	G	G	G	G	G	L
L	G	x	x	x	x	x	G	L
L	G	x	x	x	x	x	G	L
L	G	x	x	x	x	x	G	L
L	G	x	x	x	x	x	G	L
L	G	G	G	G	G	G	G	L
L	L	L	L	L	L	L	L	L

Figure 4.2: Individual plot with Guard rows and net plot

Key: L = Guard of the guard row plants; G = Guard row plants; x = Sampling plants

4.2.2 Field data collection and spraying

Each plant was given a number during the transplanting to ensure that it had an equal and independent chance of being sampled. A total of 20 bottle-tops numbered from one to twenty were used to randomly select 10 plants to be sampled in each plot. It has been predetermined by the researcher and his field assistant that if bottle tops face up and show numbers after shaking and throwing them on the ground then the plants which correspond with the numbers on the bottle top will be sampled. Data collection was weekly for 13 weeks. Data collection started early morning between 6:30 to 7:00 to avoid late sampling when the sun is hot. A total of 10 plants randomly selected were sampled from the net plot of the inner most 20 plants. Treatment applications followed immediately after completion of the data collection.

The whole plant area was checked for DBM. One mature leaf (preferably the third leaf from the top) was selected for scoring aphids and diseases. Aphid scores were classified as: 0 = No aphids, 1 = a few aphids, 2 = several colonies, 3 = half of leaf covered, 4 = sever attack, $^{2}/_{3}$ of leaf covered, 5 = entire leaf covered with sooty mould. Other insect pests and diseases apart from the target ones (DBM, Cabbage aphids and cauliflower mosaic virus) were also recorded. Sampling of non-target insect pests was based on larval, pupae and adult counting, while virus sampling was based on scoring as: 0 = no disease, 1 = 1-15% leaf area affected, 2 = 16-30% leaf area affected, 3 = 31-50% leaf area affected, 4 = 51-70% leaf area affected and 5 = 71-100% leaf area affected.

4.2.3 Harvesting

Yield was monitored continuously for harvesting. Mature leaves from both guard rows and sampling plants were harvested simultaneously but the inner most 20 sampling plants were harvested separately from the guard rows. Marketable leaves were classified as those which are clean and free from insect pest and diseases infestation and fit for human consumption. Unmarketable leaves were categorized as those which are not suitable for human conception. The Number of marketable and unmarketable leaves from the net plot were counted and weighed after completion of each plot's harvest and put in different plastic papers. Data was recorded in a prepared yield data sheet.

4.2.4 Data analysis

Insect pest population and diseases occurrences data as well as the harvested marketable and unmarketable number of leaves and their weights were entered in a computer using Excel spreadsheet. Averages, count and sums from variables were summarized. GenStat 7^{th} edition was used to analyze the entire data to examine differences between treatments. The value of using GenStat's ANOVA for analysis is the clarity and display of results, the tool also estimates missing values automatically.

As part of the ANOVA analysis, Normality and homoscedacity of all data was checked and residual graphs were drawn. Average of both DBM numbers and aphid scores were summarized before the analysis. Pest data (number of DBM, and other insects pests except aphids, score of aphids and diseases and count of natural enemies collected from the field) was analyzed using non-parametric Kruskal-Wallis analysis of variance

(ANOVA). Impact of treatments of natural enemies was assessed by comparing differences between treatments.

For analyzing the marketable number of leaves, results were transformed to square roots for underlining data normality (Table 3.4). And this could be relevant because when the interested variables are from some form of count data then square root transformation is often effective (Mead *et al.* 1993). Therefore the count data from yield are presented in square root transformation resulting data rather than its original means, this was chosen because the number of leaves harvested data analyzed are based on square root transformation.

4.3 RESULT

4.3.1. Results of insect pests (DBM and aphids), diseases and natural enemies in the field

The effectiveness of reduced frequency of chemical insecticide (Diazinon) against *Plutella xylostella and Brevicoryne brassicae* in the field was evaluated. Different result of DBM and Cabbage aphid infestation was found from weekly chemical spray and other treatments. One week chemical treatment alternated with chilli on the following week did not reveal better result than one week chemical spray alternated with two weeks chilli and/or biweekly diazinon spray.

Analysis of Variance (ANOVA) was carried out for analyzing the average number of DBM and average score of aphids. The experiment continued for 13 weeks. The number of DBM larvae in field was limited for the first four week but increased from the 5^{th} to the 13^{th} weeks. Aphid infestation started from the first week of transplanting and the sampling continued until the end of the experiment. Aphid infestation reached its highest score between week 5 to week 11.

Weekly chemical treatment (T1) had the least score of aphids and was significantly different from all the other treatments ($P<0.05$). The control (T6) showed the highest mean of aphid score and was significantly different ($P<0.05$) from all the other treatments. One week diazinon and next week chilli treatment (T3) was not significantly different from the bi-weekly diazinon sprayed plots (T4) as well as the one week diazinon and the next two weeks the chilli sprayed plots (T2) ($P>0.05$). The mean number of DBM and aphids in diazinon sprayed once in every three weeks treatment (T5) was significantly higher than in all the other treatments and also was significantly lower than the control treatment (Table 4.1).

The mean number of DBM compared among treatments revealed that the control treatment (T6) had the highest number while the diazinon treatment had the lowest. The mean number of the control treatment was significantly different from all the other treatments and the mean number of the diazinon treatments was also significantly different from the rest of the treatment. The diazinon spayed once for every three weeks was also significantly dissferent from all the other treatments. The other three treatment means were not different from one another but significantly lower and higher than the control and chemical treatment means respectively (Table 4.2).

Non-parametric test using Kruskal-Wallis-One-Way analysis of variance (ANOVA) was used for analyzing DBM and *Brevicoryne* insect pests. The number of DBM and aphid scores varied significantly between the treatments ($P<0.001$), On the other hand there was a there was a borderline significance ($P=0.05$), for the disease (virus) occurrence in the field.

Table 4.1: comparison of *Brevicoryne brassicae* score among treatments

Treatments	mean ± SEM
One week diazinon and one week chilli	0.435 ± 0.025a*
Bi-weekly diazinon	0.454 ± 0.028a
One week diazinon and 2 weeks chilli	0.404 ± 0.025a
Diazinon once every 3 weeks	0.589 ± 0.031*
Weekly Chemical	0.340 ± 0.022*
Control (no spray)	0.748 ± 0.043*

Means with asterisk are significantly different from each other $P<0.005$, while means labeled with the same letters are not significantly different from each other

Table 4.2: comparison of DBM present among treatments

Treatments	mean ± SEM
one week diazinon and one week chilli	4.237* ± 0.230a
Bi-weekly diazinon	4.740 ± 0.249a
One week diazinon and 2 weeks chilli	4.140 ± 0.236a
Diazinon once every 3 weeks	5.112* ± 0.282
Weekly Chemical	3.196* ± 0.195
Control (no spray)	6.458* ± 0.314

Means with asterisk are significantly different from each other P<0.005, while means labeled with the same letters are not significantly different from each other

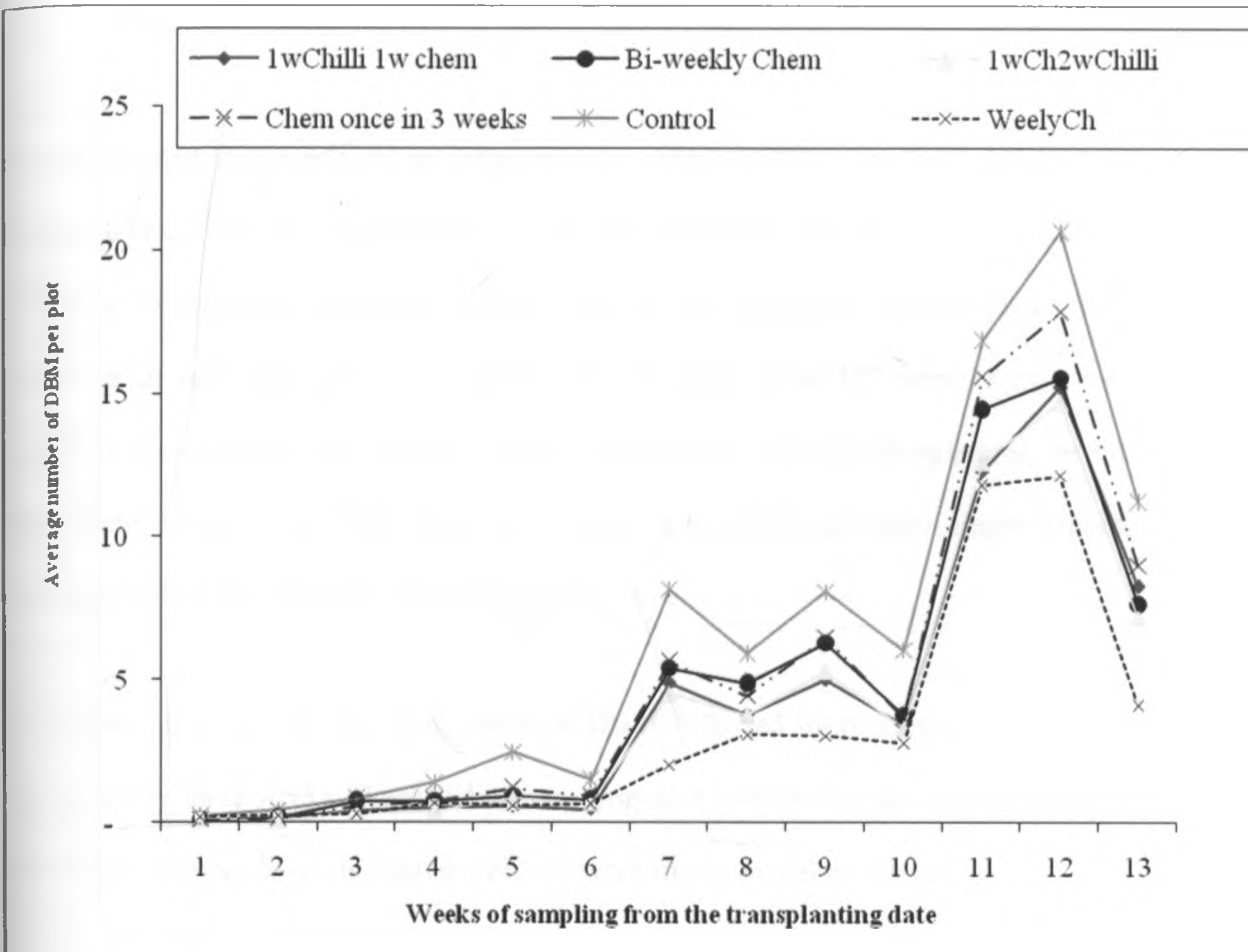


Figure 4.3: Average number DBM larvae per plot according to treatments

During the first four weeks of sampling, the population of DBM in the field was very limited. The number increased at the 7th week and remained more or less equal until the 10th week of sampling. Again the number went up and reached its highest peak on the 12th week of sampling and then, it dramatically dropped at the 13th week (Figure 4.4). Although the sampling and spraying started immediately after the transplanting for this experiment, based on the field observations control of DBM infestation might become necessary before the 7th week from transplanting date.

Unsprayed plots had the highest number of DBM followed by plots sprayed diazinon once in every three weeks. Weekly diazinon sprayed treatment showed the lowest DBM infestation followed by plots treated with one week diazinon and next week chilli.

Aphid infestation although very mild started immediately after transplanting and increased progressively until the infestation reaches its peak on the 6th to 8th week after transplanting (Figure. 4.4).

The weekly diazinon sprayed plots showed the least DBM and aphid infestations. However, the diazinon sprayed biweekly also reduced DBM and aphid infestations. Bi-weekly diazinon application was not significantly different (P >0.05) from the one week diazinon application and the next week chilli application as one treatment.

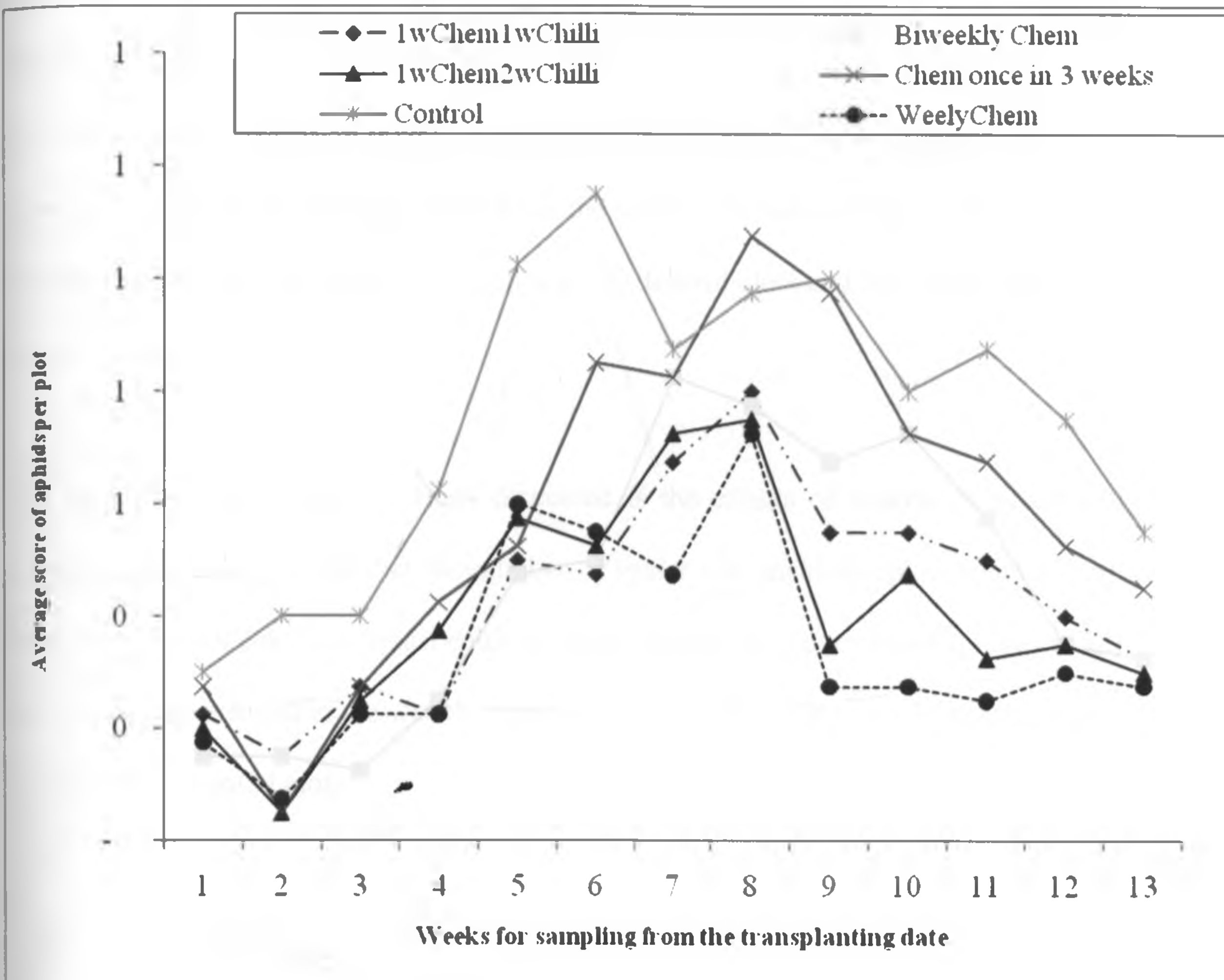


Figure 4.4: Average *Brevicoryne brassicae* score per plot according to six treatments (2003 short rains field experiment)

Although it might not be a conclusive answer the evaluated treatments have borderline significant effects on the occurrence of virus (P=0.05) (Fig. 4.5). The control treatment mean and the diazinon spray once every three weeks mean were not significant (P>0.05), and both treatment means were almost equal means virus (1.587 and 1.594 respectively). The weekly diazinon treatment has equal mean virus with one week diazinon and next two weeks chilli treatment (1.281 and 1.294 respectively). The significant difference between treatments means might have been the result of aphid infestation, hence aphids are virus vector, and infestation was high with the control plots and also in the plots with two weeks without spray.

One important aspect that this study discussed is the effects of treatments on natural enemies. The result showed that the number of spider and ant in the plots sprayed with once every three weeks were quasi equal to those found in the control (not sprayed at all) plots, while those found in the weekly chemical sprayed plots were less than half of those found in the untreated plots.

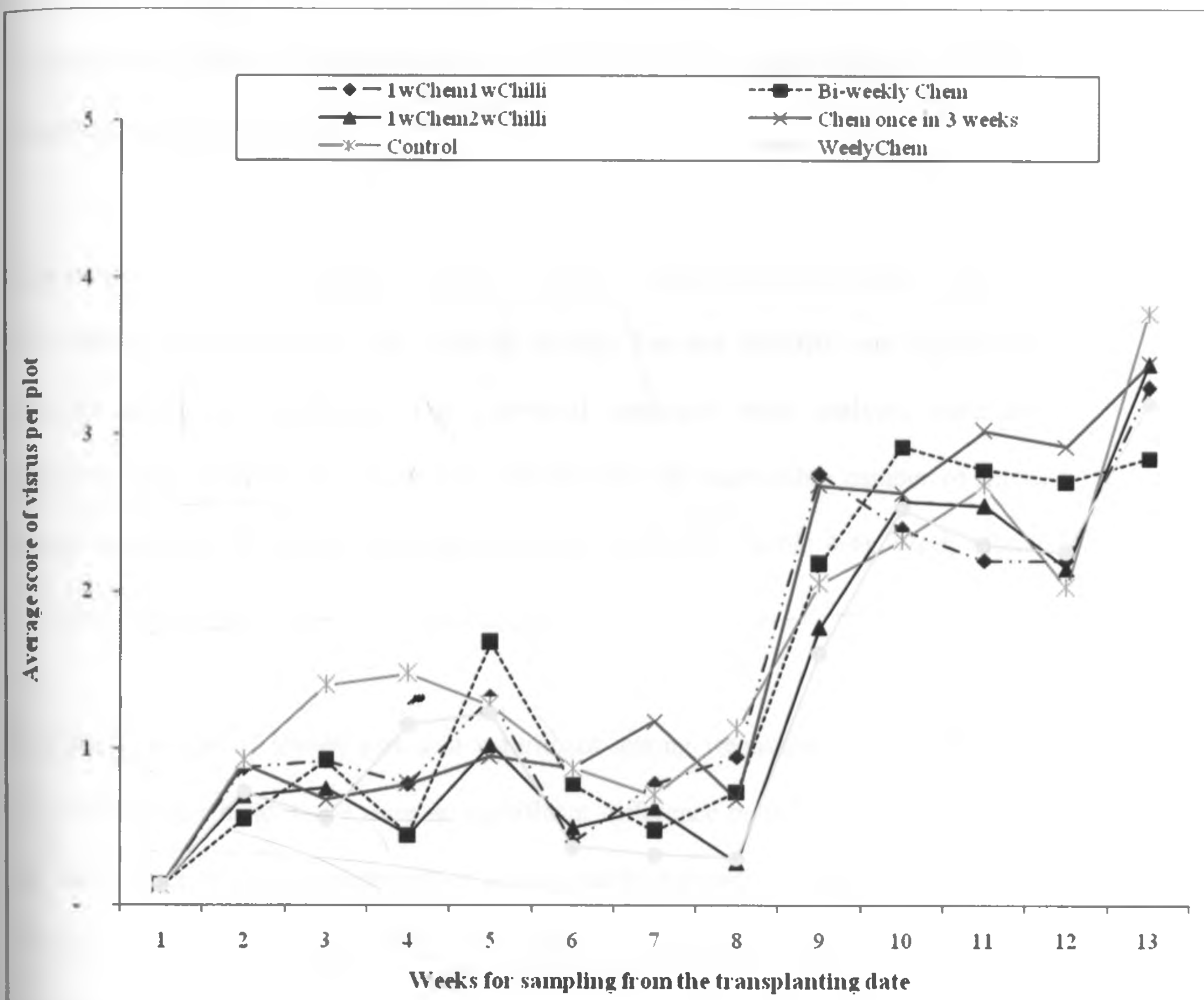


Figure 4.5: Virus score pattern per plot according to six treatments for 13 weeks of kale field sampling

4.3.2 Yield Results

Yield result indicated that alternating botanical products with chemical spray in the field weekly or two weeks may yield the same as the weekly chemical sprayed plots. Chemical treatment alternated with chilli also indicated better yield than the unsprayed. The effects of the different treatments could be realistic because the total number of leaves and their weights were not significant.

Infestations observed during the life-span of the experiment were high. The yield marketability based on insects and diseases damage free and maturity was significantly different among the treatments. The individual treatment mean analyses were also significant. The results from *square root* ANOVA for the marketable number of leaves showed significant difference between treatments (P<0.001) (Table 4.4). Week effects were also significant.

Marketable weight of leaves was also significant among treatments (P=0.044) (Table 4.5). On the other hand, there were no significant difference between the treatments for the total number of leaves (marketable + unmarketable) harvested compared with control treatment (P=0.464) (Figure 4.6) and similarly the total weight (marketable + unmarketable) of the leaves did not show any significance among treatments (P=0.151).

ANOVA showed that there was significantly more marketable number of leaves from the weekly diazinon treated plots. However, there was no significant difference between the weekly diazinon treated plots and one the week diazinon and the next two weeks chilli treated plots (P>0.05). There was no significant difference between the control treatment mean and the means from bi-weekly diazinon treatment and the once in every three weeks diazion treatment (P>0.05), although there was a much higher yield from the latter two treatments compare to the control treatment.

Table 4.3: Illustration of the effects of square root transformation on the marketable number of leaves per block according to the different treatments.

Treatments	Data	Blocks			
		A	B	C	D
Bi-weekly diazinon	Sum of marketable no. Sum of sqrt marketable no.	256 30	248 28	204 25	111 15
Diazinon ones every 3 weeks	Sum of marketable no. Sum of sqrt marketable no.	251 29	189 25	183 24	147 22
One week diazinon/ one week chilli	Sum of marketable no. Sum of sqrt marketable no.	208 25	230 27	208 24	210 25
1week chemical 2weeks chilli	Sum of marketable no. Sum of sqrt marketable no.	264 31	322 34	195 25	235 27
Control	Sum of marketable no. Sum of sqrt marketable no.	195 25	204 26	127 21	120 16
Weekly diazinon	Sum of marketable no. Sum of sqrt marketable no.	368 35	290 33	189 25	214 26

As explained in materials and methods, conducting ANOVA, there are three assumptions

1- The data is continuous and normally distributed
2- Standard Errors of treatment Means (SED) are homogenous
3- And the effects of the factor levels are assumed to be additive

However, "count data are prone to show heterogeneous variances" (Mead *et al.*, 1993). Therefore when such data is transformed to either *logarithm* or *square root* transformation give better consistency to assumptions needed for ANOVA. That is why the marketable number of leaves which is a count data was transformed to *square root* for better analysis.

Table 4.4: Marketable number of leaves per plot

Treatments	mean ± SEM
Bi-weekly diazinon	6.165 ±0.938ac*
Diazinon ones every 3 weeks	6.248 ± 0.779ac
One week diazinon/one week chilli	6.290 ± 0.964ac
One week diazinon/2 weeks chilli	7.274 ± 0.840b
Weekly diazinon	7.448 ± 0.850b*
Control (no spray)	5.461 ± 0.839ac*

Means with asterisk are significantly different from each other (P<0.005), while means labeled same letters are not significantly different (P>0.005) from each other, analysis are based on square root transformed values.

Table 4.5: Marketable weight (g) of leaves per plot

Treatments	mean ± SEM
Bi-weekly diazinon	768.8 ± 240.4a*
Diazinon ones every 3 weeks	726.9 ± 191.2a
One week diazinon/one week chilli	1138.4 ± 339.6b
One week diazinon/2 weeks chilli	1278.8 ± 356.0b*
Weekly diazinon	1053.4 ± 304.9b
Control (no spray)	727.5 ± 254.1a*

Means with asterisk are significantly different from each other P<0.005, while means labeled same letters are not significantly different from each other, analysis are based on square root transformed values

The unmarketable number of leaves harvested (Table 4.6) revealed significant difference between the treatments ($P<0.001$, $P=0.002$ respectively). Yield reduction in both quantity and quality may be caused by the insect damage and diseases infestation. Analysis also showed that the effects of weeks were also different and this could have been due to physical factors' influence such as rainfall, humidity and temperatures of the area.

Table 4.6. Unmarketable number of leaves per plot

Treatments	mean ± SEM
Bi-weekly diazinon	8.132 ± 0.520a*
Diazinon ones every 3 weeks	8.617 ± 0.382a
One week diazinon/one week chilli	8.120 ± 0.559a
One week diazinon/2 weeks chilli	7.714 ± 0.532b
Weekly diazinon	7.469 ± 0.542b*
Control (no spray)	9.725 ± 0.403c*

Means with asterisk are significantly different from each other $P<0.005$, while means labeled same letters are not significantly different from each other, analysis are based on square root transformed values.

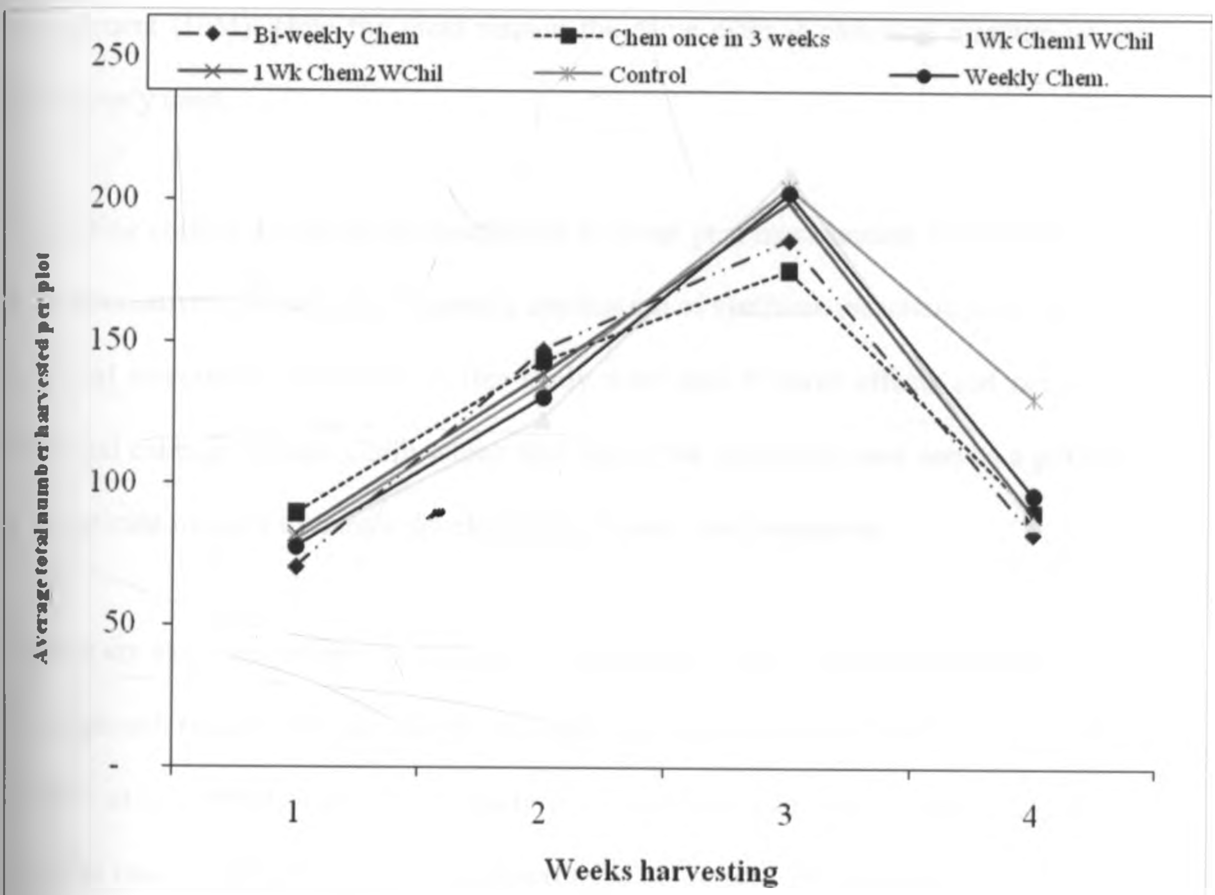


Figure 4.6. Total number of leaves (marketable + unmarketable) per plot per treatment

4.4 DISCUSSION

Reducing frequency use of chemical insecticides is important if the resulting yield will remain the same. Therefore, the results which were obtained from the present study suggest that the application of diazinon once in every three weeks and alternated with chilli has equal effects when used on weekly basis, and the option here is to use chemical insecticides less frequent. The results of the present study also indicate that the reduced frequency use of chemical insecticide may form an important part of integrated pest management (IPM) while the yield remain the same even if chemical insecticides are aggressively used.

Alternating chilli with chemical insecticides in insect pest management in the field could be an alternative to reduce the frequency application of synthetic insecticides on the crop. Botanical insecticides evaluated in this study were able to have effects and control on DBM and cabbage aphids. Chilli which was one of the botinicals used can be a potential of insecticide rotation to reduce development of insect pest resistance.

Farmers are eager and willing to was new techniques for pest control and especially if the new approach reduces the farm financial input while the return will not be compromised (Brewer *et al.*, 2004). The present study employed the reduction of frequency use of chemical insecticides which may not compromise the return. The approach of the present study will also help decreased health hazard, pollution of the environment, effective natural control mechanism and reduction of insect resistance to chemical insecticides.

Three of the strategies of pesticide resistance management are (a) modification of pesticide usage; this recommends non-continuity application of the same pesticide or changing the mode of action of same pesticide, (b) using a reduced rate of pesticide, and (c) the use of combined control tactics such as using alternative pesticides (Norris *et al.* 2003). In line with the previous studies, the present study agrees with these pesticide resistance management techniques and found that the reduced frequency application of chemical insecticide and using botanicals as alternating treatments would be a complement technique of management resistance of insect to insecticides. In addition, Conserving natural enemies and beneficial insects is important due to their pivotal role in insect pest management and biodiversity, but widespread and frequency use of synthetic insecticides is one of the greatest impediments for the natural enemies' conservation (Benbrook, *et al.*, 1996).

Katsvanga and Chigwaza (2004) reported that although synthetic insecticides agreeably have a high knock-down capacity, they have also proven not to be the absolute solution for insect pest control mechanisms. Plant derived solutions can also be very effective in control aphids on vegetables. Plant materials can be more effective if applied immediately after preparation and may be a higher concentration, although there is a possibility of phytotoxicity.

Chilli extract can be used to control both DBM and cabbage aphids, and can reduce damage caused by both insect pests. Chemical and synthetic insecticides are still and will be playing an important role of insect pest control, but their frequency of application can be reduced for rotating with chilli product. The resulting yield will not be reduced if chilli solution and chemical spray applications are rotated on the kale crops.

Chemical rotated with botanical product in insect pest control can effectively reduce insect pest resistance and enhance the role of integrated pest management. Thus the present study recommends the continuation and adoption of rotating chemicals with botanicals. Farmers' might be reluctant for the adoption of this methodology due to the workload and the extra cost which will be involved. However, with better training and proper extension services will motivate and encourage farmers' awareness in testing and adopting new techniques and technologies such as the one recommended in this study.

CHAPTER FIVE

5.0 REPELLENT EFFECTS AND KNOCK DOWN CAPACITY OF CHILLI EXTRACT ON DIAMONDBACK MOTH (*Plutella xylostella* (L.)) (Lepidoptera: Plutellidae)) UNDER LABORATORY EVALUATION:

5.1 INTRODUCTION:

Assessment on the knowledge of local farmers carried out by this study revealed the most farmers applying the organic methods in Kabete location use chilli as pest control component. Thus these investigations were initiated to test some of the local plants which the communities believed possess insecticidal properties such as chilli plant.

Zhang *et al.* (2004) carried out experiments on leaf dipping in ginger oil to test the efficacy of the plant extract and its repelling effects against whitefly adults in tomato fields. The result of the experiments showed that tomato leaf disk dipped in ginger oil repelled whiteflies at concentrations of 0.5, 0.7 and 1% but not at concentrations <0.5%. It also showed that repellency increased with increasing ginger oil concentrations. However, the experiment showed no significant effect when ginger oil was sprayed on the leaf disks instead of dipping the leaf in the oil.

Due to chemical insecticide resistance by many of insect pests there has been growing interest in plant-derived compounds as alternative to the use of synthetic insecticides in pest control programmes (Gonzáles-Coloma *et al.*, 1994. Addor, 1995; Cornelius *et al.*, 1995).

Smith (1979), Sharma *et al.* (1994), explained direct choice tests and noted that in order to reveal potential insect repellent properties of natural extracts it is important to screen their efficacy in simple laboratory experiments. For subterranean termites, direct choice trials with extract treated and solvent treated filter paper disks proved to be an adequate method. In those experiments it was found that test paper disks impregnated with different concentrations of formulated isoborneol, formulated cedarwoodoil, plantoil and bodyoil significantly repelled groups of *R. santonensis, R. virginicus, C. formosanus,* and *S. intermedius* workers.

Travis and Rick (2000) conducted a study to evaluate toxicity of several insecticides to one of the DBM natural enemies adult *Diadegma insulare* (Cresson) and DBM itself. Leaf dipping and larval dipping bioassay for DBM was carried out and larval mortalities were assessed. Larval deaths were significantly higher at field rates with carbayl, permethrin, spinosad, and tebufenozide when compared with *Bacillus thuringiensis*. In the leaf dipping and residual bioassays, both permethrin and spinosad caused 100% mortalities to DBM larvae and adults respectively.

Ovipositional preference and larval survival experiments of DBM in screen houses were conducted by Badenes-Perez *et al.* (2004), host plant examined as trap crops were glossy and waxy collards, *Brassica oleracae* L. variety *acephala*; Indian mustard, *Brassica juncea* (L) Czern; and yellow rocket, *Barbarea vulgaris* (R.Br.) variety *arcuata*, for the multiple-choice test, result showed that more eggs were laid on glossy collards, Indian mustard and yellow rocket and number of eggs were 3, 18 and 12 times higher than on cabbage respectively.

The experiment showed that chilli crude extract can inhibit *Helicoverpa armigera* larval feeing (Khalif, 2000). This caused starvation of the larvae and to death.

The objective of this study is to assess the efficacy of chilli extracts in the laboratory by carrying out laboratory bioassay, and based of the local knowledge the study aimed to determine the optimum dose that can effectively repel or deter DBM feeding.

5.2 MATERIALS AND METHODS

To assess the efficacy of chilli extract in a laboratory, freeze-drying method was used; kale nursery was planted in Chiromo campus. DBM was collected from the field and reared in a laboratory under room temperature, humidity and photoperiod and finally leaf-dipping bioassay was carried out.

5.2.1 Experimental plants

Kale leaves were used for the experiments described in this chapter, for egg laying by the reared DBM in screen cages. The laboratory experiment was carried out at the Zoology Department of the University of Nairobi's laboratories. Kale seeds were bought from Kenya Seed Company. The nursery was prepared in an open area fenced with wire mesh adjacent to the Zoology department green houses. Seeds were sown in trays filled with fertile soil; lines were traced in the trays and seeds were sown along the lines. Two weeks after germination, seeds were transferred into flower pots and each seedling was transplanted in a flower pot filled with soil to which DAP had been added. The Seedlings were watered on a daily basis and insect and diseases infestations were controlled by hand crushing and plant washing. CAN was added in the flower pots four weeks from the transplanting date.

Plant washing as a means of removing pests from plant parts for sampling and monitoring was conducted such as methods described by Burris *et al.* (1990), Hossain, (1992), Micinski *et al.* (1995), Jedlickova, (1997) and Tze-kann (1999). However, little quantitative findings and information on the effectiveness of plant washing as a pest management technique to keep insect pests below the economic threshold level had been published (Stewart and Peterson, 1960; Parhet *at al.*, 1987; Whiting *et al.*, 1998). However, Stoyenoff (2001) discussed low impact and inexpensive means of pest management and recommended plant washing with tap water as a safe and easy method that may be appropriate for keeping aphid populations or other insect pests such as mealybugs and mites at sub-economic level.

Thus the plant washing method was applied to prevent aphid population build up in the kale nursery. To controll other insects and diseases, mechanical control methods such as hand picking and removing diseased plants from the nursery was used. Plant monitoring was carried out in very morning and afternoon to ensure that the nursery plants were healthy and suitable leaves were available for laboratory experiments.

5.2.2 DBM (*Plutella xylostella*) Collection

In order to obtain enough DBM larvae for the experiments, insect (DBM) collection and rearing was carried out. DBM larvae and pupae were collected from unsprayed Kale and Cabbage fields at University of Nairobi's Kabete research ground. During field collection DBM larvae were removed from Kale and Cabbage leaves using small soft-bristle paint brushes. The field collected larvae were kept under normal room temperature and humidity and fed on natural diet (Kale leaves).

5.2.3 DBM rearing and preparing natural diet for DBM larvae

DBM rearing was carried out in a laboratory adopting a method discribed by Rowell (2004). Unsprayed Kale leaves were collected from the nursery, and the leaf petioles were trimmed with a knife. Cottonwool balls were soaked in water and squeezed to remove some of the water but left moderately wet. The cotton was wrapped tightly on the cut base of the leaf petioles and were then wrapped with a small plastic bag and sealed with a rubber band. Thus the leaf could remain fresh for three to four days without wilting (Plate 5.5).

The prepared leaves and DBM larvae were then transferred into the rearing containers, each prepared leaf was put in a plastic rearing container of 21x8 cm. 15 larvae were introduced on to a leaf in each rearing container and every leaf was replaced once every three days until the larvae pupated. The pupae were kept in cleaned and disinfected Petri dishes and placed in a screen cage until the adults emerged. Soon after the adults emerged they were fed on 50% honey solution soaked into cotton wool. Immediately after adults emerged three or four Kale leaves were put in the screen cage to allow adults to lay eggs on the leaves.

The eggs laid on the leaves were collected and kept in clean and disinfected containers for emergence. The newly emerged larvae (F1) were removed from old leaves using a soft camel brush and transferred to new Kale leaves. The larvae were kept under natural photoperiods and at room temperature. Third instars of these larvae were used for the experiments. During insect rearing, all the rearing containers and screen cages were protected from ants and other natural enemies. 75% alcohol and 10% hypochlorite was been used to clean and disinfect the surfaces.

Plate 5.5. Kale leaf used for rearing Diamondback Moth larvae in the laboratory. The leaf was kept alive for 3 to 4 days by wrapping cotton balls soaked with water and placing the leaf petiole.

5.2.4 Extraction and freeze drying procedures

Local communities (Kabete residents) grind chilli pods and pour on their plants, some mix the solution with soap, while others grow chilli crop inside their farms assuming that the plant repel insect pests.

Chilli pods for this experiment were bought from a local market (Wakulima), weighed and blended in a laboratory using a balance and blender. The solution was sieved using normal tea sieves, and the juice was then transferred into a metal container and put in a deep freezer for 24 hours. A freeze drier (Plate 6.5.) machine was cleaned with water and sterilized with 70% alcohol. The frozen chilli juice was transferred into the freeze drying chamber and then covered. The machine was switched on and checked three times in a day for frozen temperatures. When frozen items were noticed the machine was switched off and temperature room water was poured into the frozen chamber to remove resulting ices and excess water which comes out the outlet tube. This process was repeated four times until the frozen gauge came to room temperature. While this process continued, the containers containing chilli mixture was kept under deep freezer. The freeze drier was cleaned again with water and sterilized with 70% alcohol and the container containing the chilli mixture was put in back to the freeze drying machine. The aim of this method was to obtain pure chilli powder extracts with which to carry out bioassay. The material was left in the freeze drier for three to four days, and each day the resulting ice was removed from the freeze drier in order to avoid blockage and allow the process to continue smoothly.

After completion of the process, the dried chilli material was a pure chilli extract. The powder extract was then removed from the freeze drier, weighed and wrapped in the aluminum foil, and stored in a fridge until the execution of the experiments. When the experiments were ready to start, the chilli powder was again put in the freeze drier for one hour to remove any frost and water.

The fundamental process of freeze drying is as by (Kabaru and Gichia, 2001) freezing which provides a necessary condition for low temperature drying. After freezing the product was placed under vacuum, this enabled the frozen solvents in the chilli material to vaporize without passing through the liquid phase, this process is known as sublimation. The third step was to apply heat to the frozen product to accelerate sublimation, then condensation completed the separation process, this was low temperature condenser plates remove the vaporized solvent from the vacuum chamber by converting it back to solid.

Plate 6.5. **Freeze drier machine used to remove water from chilli materials. This machine is at Zoology laboratory, School of Biological Science UoN.**

5.2.5 Leaf Dipping Experiment

The leaf dipping experiment was carried out so as to determine the efficacy of pure powder chilli extract. Kale leaves were dipped in different concentrations of pure chilli powder dissolved in tap water. Fresh third instars larvae were then introduced on the treated leaf and left for 72 hours after which they were removed.

5.2.5.1 Dose preparation, larval introduction and data collection

Chilli powder was weighed to make 5 different concentrations with an incremental factor of 1.26 of the concentration at intervals of 0.1 logarithms. The treatments were 70g/l (70 grams of pure powdered chilli dissolved in one litres of water), 88.13g/l, 110.92g/l, 139.64g/l, 175.79g/l while the sixth treatment was control which was not dipped. The test was conducted in duplicate, and two cleaned leaves were dipped in and used for each treatment. 10 third instars larvae were introduced onto each leaf thus 20 larvae were tested in each treatment as block 1 and 2. The experiments were then repeated to make the experimental larvae 40 for every treatment. Therefore each treatment consisted of four blocks of 10 larvae each.

Before the larvae were introduced on the leaf, the area of the leaves was measured using 1mm graph paper (Plate 7.5). The leaves were dipped in the solution for 60 seconds and allowed to dry, while control leaves were not dipped. After leaves dried, cotton wool soaked with plain water was wrapped on the leaf base using a plastic bag and tightened with a rubber band. Two pellets of CAN were put near the leaf petiole to keep the leaf alive. The leaves were then placed in a plastic container of 21x8 cm and larvae were introduced onto the leaves (Plate 8.5). Facial tissue paper covered the floor of the experimental container, and a rubber band was used to hold the cover in place. The larvae were removed from the leaves after 72 hours and the leaf area eaten by the larvae was measured using the same trace on the graph paper. Any larval mortality was recorded, and the place where larvae were found. (Whether they were on the leaf or off the leaf) was recorded as a measure of the repellency capacity of each treatment. Data was entered using excel for statistical analysis.

Plate 7.5. Experimental leaves: leaves were dipped in chilli solutions and experimental larvae were introduced to feed on. Before larvae introduced the leaf area was measured. The above experimental two leaves for instances show two blocks of treatment two (88.1 g/l)

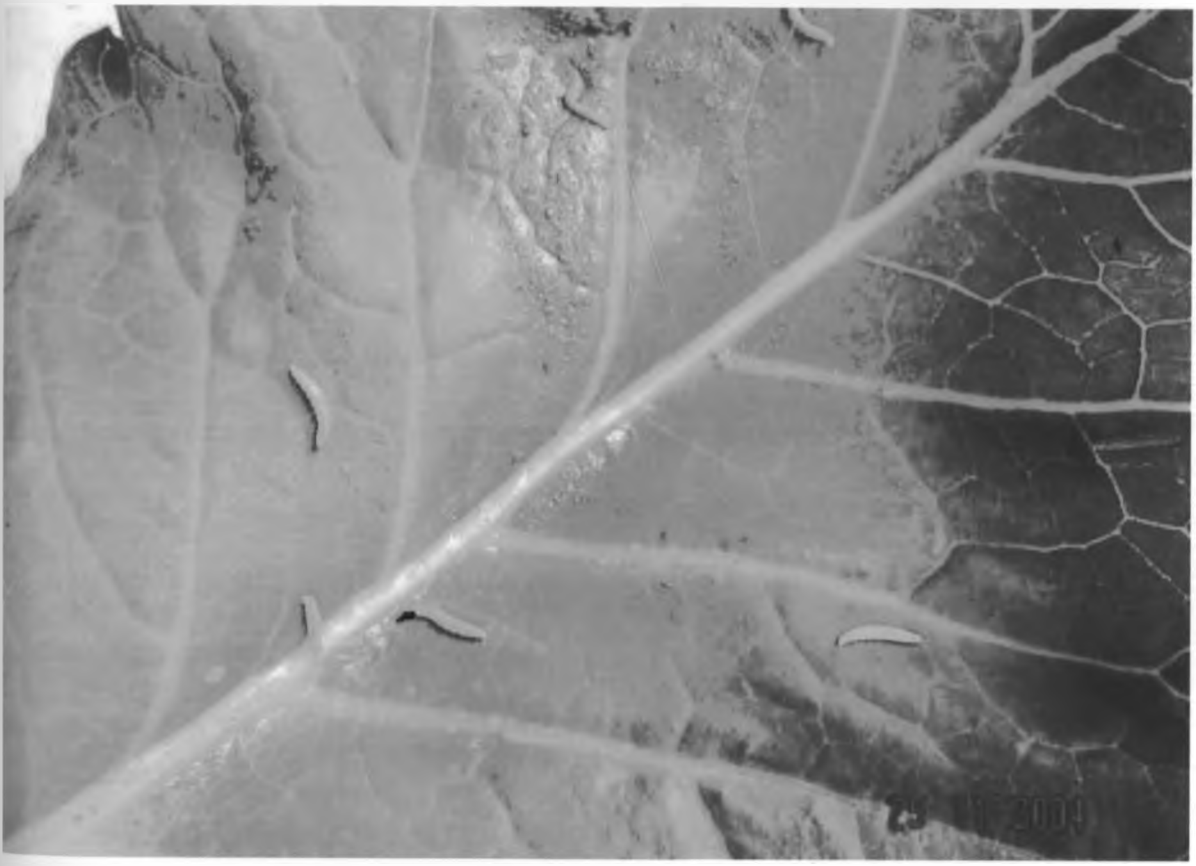


Plate 8.5. DBM larvae introduced on a chilli treated leaf. The larvae remain on the treated leaf or in the container where the leaf was placed for 72 hrs to measure leaf area eaten by the larvae and calculate. After 72 hrs the larvae were removed from the leaf and experimental container.

5.2.6 Data Analysis

Data on the area consumed by the larvae and larval mortality were entered and summarized using Microsoft Excel. Leaf area eaten by the larvae data analysis was carried out using GenStat version 7, both one-way and two-way ANOVA was carried out to see difference of the treatments. Analyses of dose-response trials, treatment means comparison and analyzing them might be misleading, in this case curvilinear analysis is the most appropriate for analyzing dose-response experiment (Morris, 1999). Therefore S-Plus statistical package was used to carry out probit analysis for dose response to determine the best dose and LD_{50} for larval mortality.

Area of leaf eaten by the larvae were analysed. Analysis of variance (ANOVA) was carried out to test the difference between treatments. However, before carrying out full ANOVA the residual graph was plotted to ensure the pattern was acceptable. From residual graph plotting (Figure 5.1), the residuals have no pattern in relation to the fitted values. This indicates that the constant variance assumption is satisfied (i.e. each treatment group had similar variance making it fair to compare the groups).

To determine larval mortality and LD_{50} using probit under Generalised Linear Model the formula bellow was used:

$$Probit\ (Proportion) = a + b\ (ln\ [concentration])$$

Where a and b are constants to be estimated by linear regression. The proportion of dead larvae was plotted against concentrations and resulting sigmoid curve was linearized by log transformations (Figure 5.3).

5.3 RESULTS

The experiment involved a comparison of five treatment levels of chilli with response variable being area of leaf (Kale) consumed. The preliminary data summary and analysis in Microsoft Excel showed that the control had the highest area of leaf eaten while 175.79 g/l treatment of chilli displayed the lowest area eaten by the introduced larvae. From the box plot below (Fig. 5.2), it can be seen that the control treatment had the highest area of the leaf consumed, and the area eaten decreased as the concentration of chilli increased to 175.79 g/l. It is very clear that the more the chemical concentration the less the area of the leaf consumed. The distribution is almost normal for data in each category of chilli concentration.

Kothari (2004) explains that in order to carry out ANOVA, the assumption must be that each of the samples is drawn from a normal population. Figure (5.1) indicates that the assumption is valid.

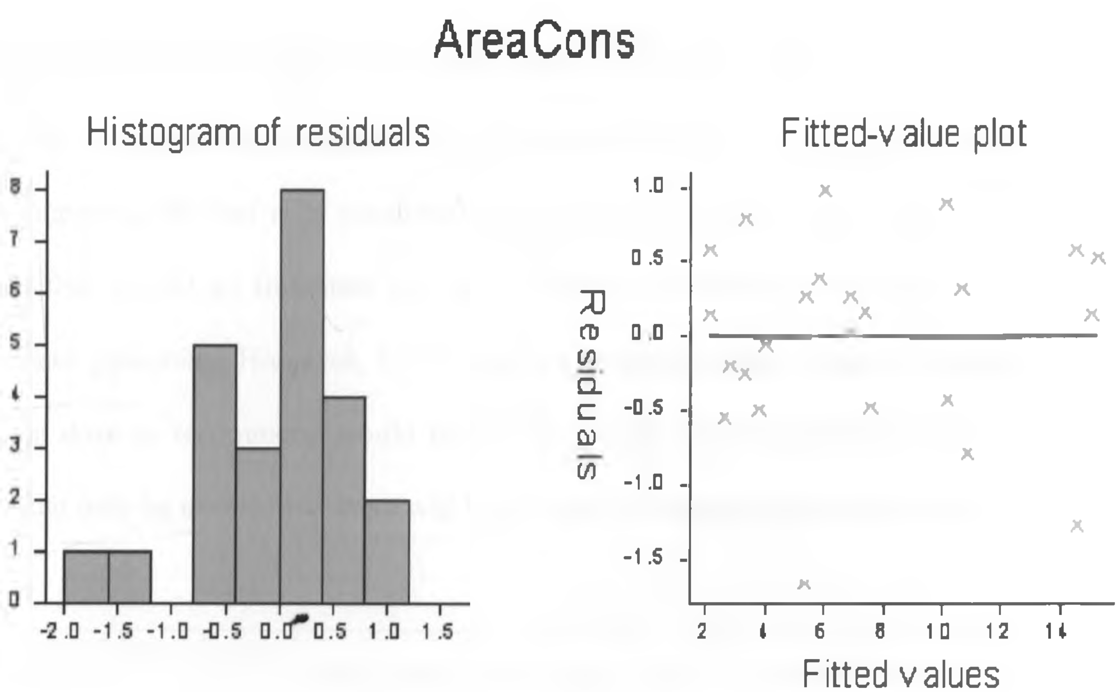


Figure 5.1. Residuals showing the normality of the data of the area consumed by the larvae (left). Residuals vs fitted values showing similar variance (right)

Based on the properties which were observed during the preliminary analysis and results, ANOVA was carried out to compare the treatments levels, and the results revealed significant differences between the treatments (P<0.001). Using the Least Significant Difference (l.s.d=1.228) to compare the treatment means for the area consumed by the larvae, all the treatment levels were significantly different except slightly for the treatment levels 139.64 and 175.79 g/l.

Furthermore, in order to determine the optimum dose of pure chilli concentration as IPM component, the treatment concentrations were transformed on the log scale and data were modelled comparing the leaf area consumed. The resultant logistic cure (Figure 5.3), recommends that 110.92 g/l treatment can be affective in controlling insect pest when used as stomach poisoning. However, 110.92 treatment showed large variation, thus the best optimum dose to recommend would be 139.64 g/l and that beyond this point the treatment could only be excess, and there will be no need to increase the concentrations.

```
*** Generalized Linear Model ***
Call: glm(formula = prop ~ ln.conc, family = binomial(link = probit), data =
DS6,
       weights = prop, na.action = na.exclude, control = list(epsilon =
       0.0001, maxit = 50, trace = F))
Deviance Residuals:
 4 5          6           7           8          9
 0 0 0.02744916 -0.03184485 -0.01754389 0.01122497
attr(, "class"):
character(0)

Coefficients:
                 Value Std. Error    t value
(Intercept) -7.179167   52.21179 -0.1375009
    ln.conc  1.236003   10.40072  0.1188382

(Dispersion Parameter for Binomial family taken to be 1)
    Null Deviance: 0.0183301 on 5 degrees of freedom
Residual Deviance: 0.0022013 on 2 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

For calculating LD_{50} the results of probit analysis above were used. The residual deviance in the above output was used to check if the probit equation model satisfied or fitted the data well. Thus comparing the residual deviance value of 0.0022013 to a chi square value of 9.21 (read from a table) at 99% accuracy and 2 d.f for the test (or 5 d.f for the number of levels n-i=6-1=5) concludes that the model sufficiently fitted the data since $0.0022013 < 9.21$.

From the probit analyses, the estimates of constants (a & b) were:

a= -7.179167 and b= 1.236003. The regression equation was thus:

Probit (proportion) = -7.179167 + 1.236003 [Ln (concentration)].

To estimate the Ln(concentration) that corresponded the LD_{50}, the equation was solved as follows:

Probit (0.5) = 0, therefore

$-7.179167 + 1.236003 [\mathrm{Ln}(LD_{50})] = 0$

$\mathrm{Ln}(LD_{50}) = {}^{7.179167}/_{1.236003} = 5.80837$. Hence LD50 = $e^{5.80837} = 333.077$ g/l.

Thus, the results from probit analyses showed that the chilli concentration that kills 50% of larvae is 333.077g/l (LD_{50}=333.077 g/l).

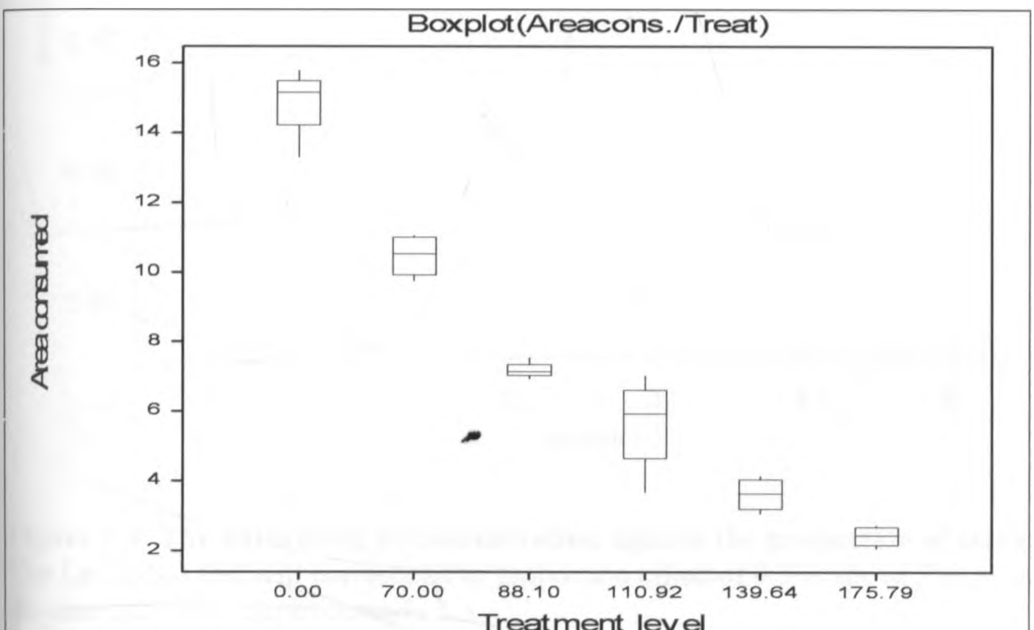


Figure 5.2. Boxplots for exploring the variability surrounding the pattern associated with the treatments to analyse treatment means of area of the leaf consumed by the larvae

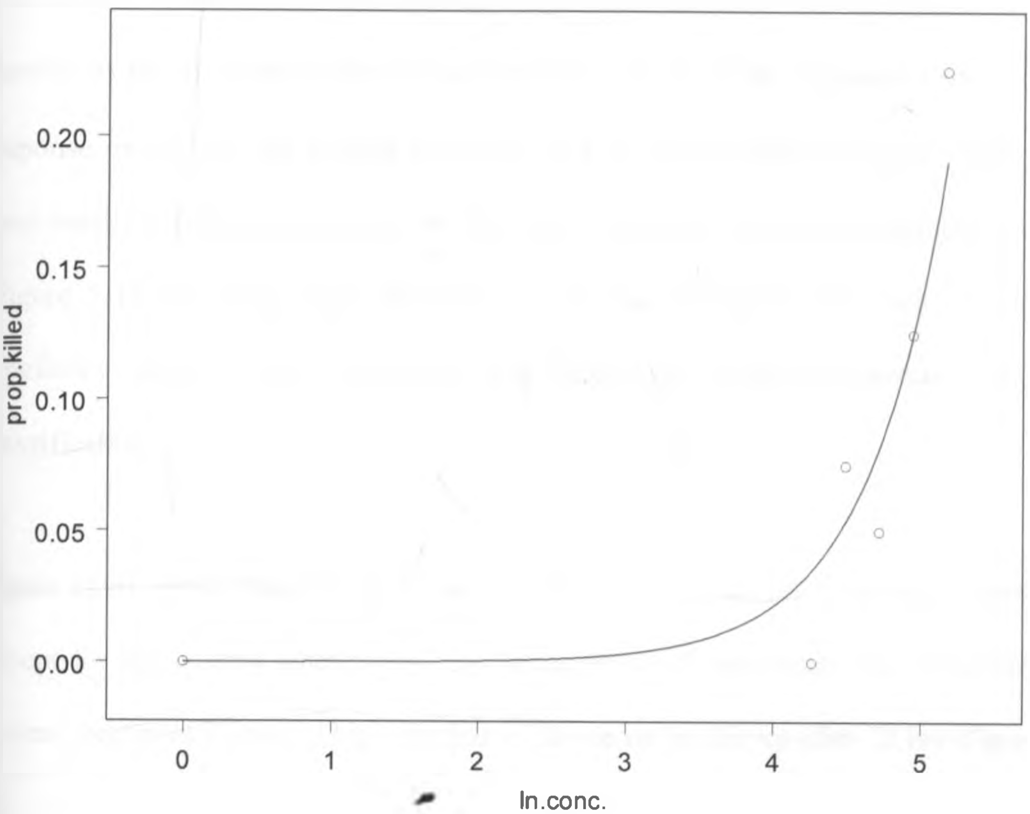


Figure 5.3. The natural log of concentration against the proportion of larvae killed. The Ln (LD_{50}) that will correspond to proportion killed of 0.5 is above 5 as estimated in the analysis and is approximately 5.8

5.3.1 Repelling capacity of chilli

After 72 hours of the treatment, the number of larvae found on and off the leaf were counted and the data was analyzed. After confirming the normality of the data, ANOVA was carried out and the results showed a significant different between treatments for the number of larvae found on the leaves $P<0.001$). Most of the treatments showed similar response except for the control treatment and treatment three (88.1g/l) which showed least repelling effects compare to all the other treatments including treatment two (70g/l) (Figure 5.4). The percentage repellence of all the treatments was then calculated and repellency class of every treatment was determined using McGovern *et al.* (1977) classification.

Figure (5.4) shows that larvae found off the leaves in all the treatments were similar except for the control where very few larvae were off the leaves. On the contrary, the control treatment showed a high number of larvae on the leaves after 72 hrs (Figure 5.5)

Results of repellence evaluation showed that T5 and T6 (139.64g/l and 175.79g/l respectively) can be classified as repellency class IV (60.1-80%), while T2 and T4 (70g/l and 110.92g/l respectively) could be within repellency class III; treatment T3 lies within the repellency class II. (Table 5.1)

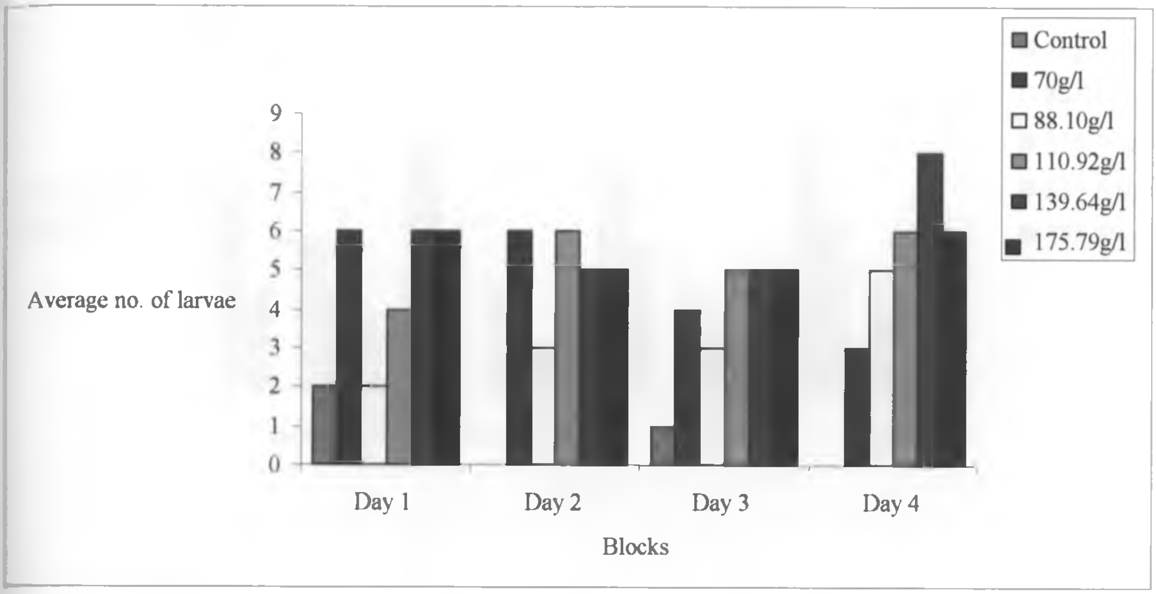


Figure 5.4. The number of live larvae found off the experimental leaves in different treatments after 72hrs

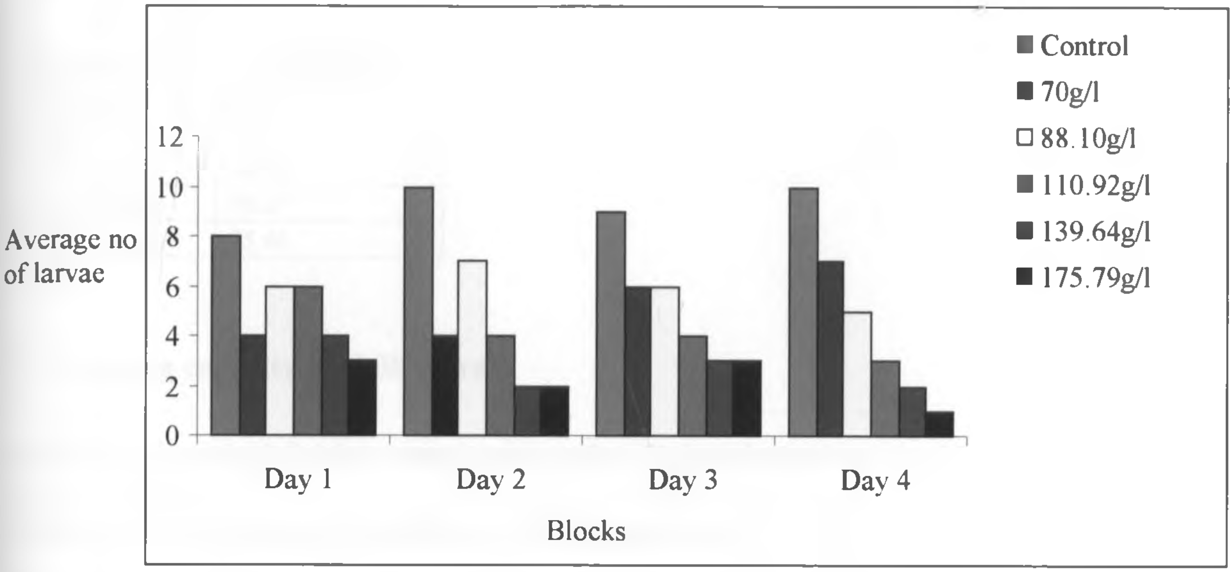


Figure 5.5: The number of live larvae found on the experimental leaves in different treatments after 72hrs

Table 5.1: Repellency % of all treatments

Treatment	% Repellency
T2 (70.00g/l)	43.24
T3 (88.10g/l)	35.14
T4 (110.92g/l)	54.05
T5 (139.64g/l)	70.27
T6 (175.79g/l)	75.68

5.3.2 Killing capacity of chilli extract

Analysis of survival fed by treated leaves after 72 hrs showed no significant difference between alive and dead larvae among all the treatments (P>0.005). The control treatment and treatment two (70g/l) showed no dead larvae, while T3 and T4 (88.10g/l and 110.92g/l) had only three and two larvae dead respectively. The highest larval mortality was recorded from T6 (175.79g/l) and showed a total of nine dead larvae (figure 5.6).

The results from the experiment showed that the freeze-drying extraction method produced biologically active antifeedant and/or repellent components against the DBM larvae. This study demonstrated that the purely extracted chilli powder exhibited feeding deterrent efficacy against DBM. The bioassay did not displayed direct killing capacity by the extract but caused DBM larvae to starve and die naturally

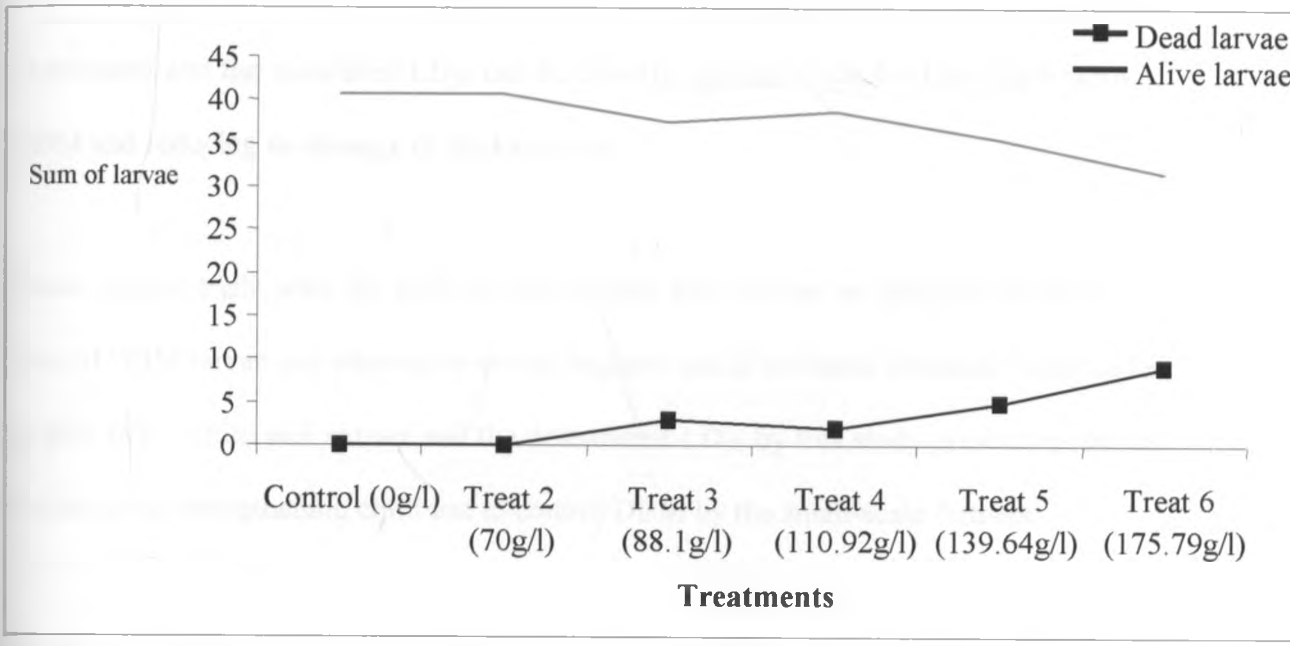


Figure 5.6. Comparison of alive and dead larvae after 72 hrs according to different treatments to demonstrate the efficacy of different concentrations of chilli extract. Larval mortality increment is direct proportional as concentration increased

5.4 DISCUSSION

Extracts from chilli pods using freez-dying methods have insecticidal properties, capacity to repel and to control local kale insect pests, thus resulting in profitable productivity. Leaf dipping experiment is more or less similar to field application. The findings of this experiment and the calculated LD_{50} can be directly applied to the field for the control of DBM and reducing its damage to the kale crop.

Direct choice trials with the chilli extract-treated leaf can be an adequate technique to control DBM larvae and alternative to the frequent use of synthetic chemical insecticides in kale field. Chilli pod extract and the determined LD_{50} by this study presents positives evidence for strengthening chilli use to control DBM by the small-scale farmers.

All the concentrations displayed repelling capacity of DBM larvae, and the repellency of the extract increased with the increase of concentration. It was observed that when larvae were introduced on the treated leaves, they started feeding but soon after, the larvae moved off the leaf to the experimental container. Continuous monitoring of larval behaviour indicated that larvae later came back on the leaf but after testing it, they moved off the leaf again.

Zhang *et al.* (2004) concluded from their study on the repellency of ginger oil extract *Bemisia argentifolii* on tomato that the product repelled whiteflies and repellency was attributed to its aroma. However, they suggested that the formulation of the extract needed to be improved with lower pytotoxicity and longer residual time. The same study recommended complete coverage, adequate deposition and the proper application time would enhance the repelling efficacy of ginger oil against whiteflies. Nevertheless, the present study agrees with Zhang *et al.*, (2004) that chilli products like many other botanicals need to be improved and their phytotoxicity be reduced in order to contribute the supremacy of IPM.

This study also agrees with Chiasson *et al.* (2004) that botanical insecticides may be a sound alternative to the more persistent synthetic insecticides for controlling major insect pests of greenhouse and field crops such as aphids, whiteflies, thrips and also lepidopterans. Chilli products like many other botanical products degrade quickly and is safe and do not contaminate environment.

Although the present study revealed the knockdown capacity of the chilli extract and best dose that can control and kill 50% of DBM larvae, it necessitates further research on the adverse effects of botanicals to beneficial insects in order to appropriately document the negative effects of chilli on natural enemies and beneficial insects.

CHAPTER 6

6.0 GENERAL DISCUSSION AND CONCLUSION

6.1 GENERAL DISCUSSION

6.1.1 Indigenous farmers' knowledge and conventional research

The farmers interviewed showed that they have different knowledge and different techniques of pest control. Almost all of them grow brassica crop for both household consumption and commercial purposes. Botanical products as pest control mechanisms are widely used in the surveyed area by the farmers in different ways and methods that suit them. Plants that have been used locally are also indigenous.

Local farmers have the capacity and knowledge to practically identify insect pests but have little knowledge of when insecticide application is necessary. They also have little understanding of the economic threshold level necessitating intervention. The survey revealed that farmers start applying insecticides immediately after transplanting or sowing seeds.

Most of the research projects which emphasise farmer participation mainly still focus on getting farmers to join the research activities conceived by scientists without involving them in the planning stage (Mengesha and Bull, 1997). And despite the growing efforts of establishing farmer field schools (FFS) and farmers' participatory research (FPR) initiatives, indigenous farmers' knowledge and why farmers are using their own approach in pest control in the central province of Kenya is poorly documented.

A noteworthy milestone is the recognition of women and giving them equal ownership with men. The role of women in farming is necessary for the unity of households

(Reynolds, 1993). Results of the present study has demonstrated that the female ratio for land ownership of the interviewed farmers constitute 65%.

Farmers were confident that the cost of chemicals compared to that of the botanicals is unattainable, while they significantly believe botanicals are more available than chemicals. And in terms of toxicity, almost all of them know chemicals are more toxic and none of them believe botanicals are toxic even those who do not use them (Table 2.3).

All the interviewees believe that botanicals need more labour input than the chemicals. In terms of farmers knowledge of either chemical or botanical preparations and applications the result did not significant difference because almost 50% believe they know chemicals are better than botanicals while other the 50% know botanicals are better than chemicals (Table 3.4).

The present study revealed that almost 50% of the farmers surveyed use botanical farming due to their interests in safeguarding the environment and reducing sickness due to synthetic pesticides. On the other hand over 18% of the interviewed farmers (Riverbank farmers group) believe that chemicals are very effective in pest control. In addition, farmers showed interest in experimenting new initiatives and changing their tradition of using one pest control component. Despite farmers' interest in participatory trials for developing pest control technology, the transfer of technology approach has been a long standing paradigm due to its top-down, institutionally developed style.

An area where this study reflects farmers' weakness is their knowledge of insect monitoring and scouting in order to determine pest density and dynamics. Research with farmers, documenting their know-how and injecting new techniques to the already existing ones will enable resource-poor farmers to effectively handle their insect pest control strategies and sustainable farming practices.

Most of the farmers interviewed believe that chemicals can cause insect resistance more than botanicals yet chemicals can kill more insect pests than botanicals. However, this might necessitate through research on the indigenous plants with insecticidal properties and their safe use and site effects on plants and environments. Active ingredients of indigenous plants need to be effectively identified under laboratory screening to minimise the use of crude extracts. Some farmers obtained training from some government institutions such as KIOF and other research organizations while some others did not have that opportunity. Organic farmers in the surveyed area believe that protecting biodiversity is important and they don't apply insect killing methods but they prefer to use repellents in order to starve insect pests and lead them to die naturally. Some other farmers have no alternative or knowledge other than using chemical insecticides to protect their crop.

One group of farmers (Kili group, Nyathuna) believe that in order to explore new insect control techniques a common demonstration plot is important. This will enable farmers to effectively engage a dramatic and lasting solution in insect pest control as well as establishment of farmers research group (FRG), which will in the future engage in participatory research with other institutions. This will easily facilitate technology transfer and its adoption.

Farmers have indigenous knowledge in farming which scientists do not know, while indigenous farmers do not know some things which scientists know, in addition there are many things which neither indigenous farmers nor scientists know (Bently, 1994, Chambers, 1991). The mechanism of integrating indigenous knowledge and scientific discoveries would perhaps provide better adoption of insect control technology and avoid knowledge conflicts between resource-poor farmers and research institutions.

The results from the present study reveal that farmers are willing to obtain techniques of organic farming from research organisations and believe they can contribute to the enhancement of such techniques. Therefore, in-depth study will verify how research organisation could engage peasant farmers with their activities in central and eastern provinces of Kenya.

6.1.2 Effects of Chilli and Marigold crude aqueous extracts against *P. xylostella* and *B. brassicae*

Results from the 2002 long rains and 2003 short rains, field experiments indicated that botanicals can be an important part of insect pest control specifically integrated pest management initiatives for diamondback moth and cabbage aphids. However, the use of botanicals specifically chilli and marigold are not yet conventionally agreed and not yet well documented at a field level. Chilli and marigold displayed different results during field experiments which were previously not clear. For instance, marigold spray displayed high phototoxicity on kale plants resulting in less marketable yield. These findings of the present study agrees with Zhang *et al.* (2004) who found that petroleum oils and plant derived extracts that have insecticidal and repellent activities against many insect pests could also have phytotoxicity effects.

Other studies have shown that botanical extracts are active against brassicas pests. Spraying sami-purified *Tagetes* spp. could kill 50% of *P. xylostella* and can cause 96% green aphid mortality (Morallo-Rejusus, 1987). Crude and semi-purified extracts of black pepper are topically more toxic than Malathion against *P. xylostella* larvae (Javier and Morallo-Rejusus 1986, Morallo-Rejusus 1987). In line with these reports, the findings from the present study's field experiments showed that the number of *P. xylostella* and *B. brassicae* could significantly be reduced by spraying chilli and the marigold crude extract at the rate of 300 g/l and 50 g/l respectively.

The results obtained from this study showed that synthetic insecticide could not significantly do better than chilli and the marigold crude aqueous extracts in terms of reducing insect pest infestation in the field but the leaf yield showed significant difference between the chemical and marigold sprayed plots. In contrast, chilli and the chemical sprayed plots were not significantly different in terms of marketable yield.

Marigold caused crop burning and damaged leaf surfaces which made mature kale leaves unmarketable and unsuitable for human consumption. The chilli sprayed plots did not show any negative effects on the crop and clean leaves were harvested. The total yield obtained was not significantly different in terms of the numbers and weights among all the treatments and this indicated that the significant difference between the marketable yields was because of the product which wassprayed on the plants.

Chilli aqueous extracts displayed similar results with synthetic insecticides. However, farmers use synthetic insecticides heavily due to promotion by the producers and insecticide traders as well as farmers attempts to increase yield with no knowledge on how to achieve this without synthetic insecticide reliance.

More sustainable and safer methods of pest and crop management exist and are being successfully used by millions of small-scale farmers in the world, resulting in more and sustainable yield in some of the most challenging agro-ecological environments (Williamson, 2003). Chilli extract could be one of a safe alternative of excessive use of synthetic insecticides due to its effects at field level as presented by this study.

The rapid biodegradability and low persistence of plant extracts can suitably be modified by appropriate formulation (Saxena, 1983). In line with this report, efforts to further development of natural products for wide application, studies on purified and active ingredients from the products are important. Chilli is a locally available crop and its production could be enhanced for the purpose of research and utilization of the active ingredients as a botanical insecticide. Laboratory screening and isolating compounds that accumulated in fresh marigold plants could enhance extraction and utilization of the bioactive components of marigold.

P. xylostella and *B. brassicae* are serious pests of crucifers that cause total defoliation and serious viral disease transmission respectively. They are resistant to many synthetic insecticides (Jimenez-Martinez and Bosque-Perez, 2004; Stoyenoff, 2001; Badenes-Perez *et al.* 2004). Since both *P. xylostella* larvae and *B. brassicae* adults are soft bodied insects without hard external cuticle, chilli extracts could cause irritation which could cause larval dropping from the plant as well as feeding deterrent by aphids and also DBM larvae. This mode of action reduces the development of insect resistance to insecticides and reduction of synthetic insecticide residue on plant and in the soil.

6.1.3 Reduced frequency use of chemical insecticides on *P. xylostella* and *B. brassicae*

Use of organophosphates and carbamates has remained a standard conventional method for insect pest control for many years (Barry *et al.,* 2005). However, after discovering synthetic insecticides, health hazard and environmental damage which they cause, other alternatives such as evaluating and certifying the efficacy of organic insecticides and plan extracts was initiated.

Chilli crude extract which was evaluated in the field experiment was able to control both DBM and cabbage aphids. Reduced frequency use of chemical application for two consecutive weeks using chilli extract and alternating chemical for the third week was as good as weekly chemical spray in terms of field infestation and the resulting yields. Therefore, if applying synthetic insecticide once in every three weeks alternated with chilli extract could result in the same yield as applying on weekly basis. The findings could therefore contribute a significant reduction of chemical insecticide.

Chemical insecticides play a significant role in crop protection but the drawback to their use is their non-biodegradability, persistence and environmental contamination as well as hazard to human health. Results obtained from the present study have demonstrated that there is possibility of reducing these risks of synthetic insecticides by reducing the frequency of application of chemicals without compromising the resulting yields.

The effects of chilli extract could be selective and specific to DBM and cabbage aphids, because the number of predators (spiders and ants) found in the plots treated with alternated treatments was similar to that found in the control treatment, while the chemical treated plots showed almost half the number of predators.

The multitactic integrated pest management approach will replace single tactics in managing resistance, resurgence and replacement of pest organisms (Norris *et al.*, 2003). The findings of this study could contribute to the easy development of multiple control strategies of insect pests.

Adoption of the findings of this study will enhance environmental quality and consumer safety. Reduced use of chemical insecticides could contribute to integrated vegetable insect pest management. This could open up and encourage further research since similar studies in the past are rare.

The total number and mean of the leaves harvested showed no significant difference between treatments. But other factors may limit the use of this technique. And as with any insect pest control technique, cross resistance, pest management goals, labour requirement of collection and preparation of chilli extracts should be taken into account when scrutinising the appropriateness of this technique.

Unlike synthetic conventional insecticides which constitute single active ingredients plant extracts derived materials constitute an array of chemical insecticides which act concertedly on both physiological and behavioural processes (Kabaru, 2001). However, some of these compounds may act as synergists for enhancing the bioactivity of certain ingredients while some others may act antagonistically to suppress some bioactivity. Based on the results obtained in this study, it is suggested that future studies concentrate on standardization of the purified chilli extracts as insect control measure.

An IPM programme for *p. xylostella* and *b. brassicae* will be more effective if it involves multiple sprays as well as combination of botanicals with chemical application. This study showed that combination of chill with diazinon is an effective control measure against DBM and cabbage aphids in kale field.

6.1.4 Repellent effects and knock down capacity of chilli extract on *P. xylostella* L. under laboratory

The leaf dip bioassay showed that freeze-dried chilli extract has significant antifeedant properties. Results revealed that higher concentration of extracts caused higher repellence, feeding deterrence and more mortality of DBM larvae although small portions of the leaf disc were consumed. This suggests that the death of larvae were mainly caused by starvation.

Other studies have found that susceptibility of DBM larvae to crude plant extracts decreases with increased larval age due to their increased detoxicative metabolism and suggest that 1st and 2nd instars larvae are the most susceptible stages (Leatemia and Isman 2004). However, the present study used 3rd instars the larvae and total larval death observed was 7.92% of which almost half of the larval death (3.37%) was recorded from the highest chilli concentration (175.79g/l). Thus this is in concordance with the past studies, and that if earlier instars stages (1st and 2nd) were used the mortality during the life-span of the experiment (72 hrs in this case) would have been higher.

Repellence effects of freeze-dried chilli extract on DBM larvae increased with the increasing concentrations. The control treatment showed 0% repellence while higher chilli concentrations i.e. 139.64g/l and 175.79g/l showed 70.27% and 75.68% respectively.

Direct dip method may not accurately reflect application in the field but since the present study's laboratory experiment was not a controlled condition but normal photoperiod and room temperature, there is high probability that the leaf dip could also reflect field application. Besides, both field and laboratory findings of the present study revealed some significant results in terms of repelling *P. xylostella* and significant yield differences between treatments.

6.2 CONCLUSION

Botanical pesticide products are far from completely replacing conventional synthetic insecticides (Isman, 1997). Some of the chemicals will and could still serve broadly in insect pest control, but botanicals and other naturally occurring insecticides should be given priority attention in researching their bioactive ingredients and standardisation in order to ensure environmental safety and reduction of damaging natural resources. Thus, based on the results obtained from the present study, the following conclusions can be made.

1. Indigenous vegetable farmers in central province of Kenya employ diverse and dynamic indigenous insect pest control techniques including organic agronomic practices.

2. The knowledge of indigenous farmers in Kenya is poorly documented and the gap between farmers and research institutions is wide.

3. Conventional synthetic insecticides are used as insect pest control measures by commercial vegetable farm owners in Kenya to enhance their productivity. In addition, some of the farmers use chemical insecticides indiscriminately to control agricultural pests even if the chemicals are registered as household sprays.

4. Chilli (*Capsicum* spp.) aqueous extracts reduce *P. xylostella* and *B. brassicae* infestations on kale and increase yields significantly.

5. Marigold (*Tagetes* spp.) could reduce *P. xylostella* and *B. brassicae* damage on kale significantly but negatively affects the yield. Fresh juice from marigold leaves could cause high phytotoxicity on plants and reduce kale production.

6. Spraying chemical insecticides on a kale field once every three weeks and alternating it with chilli aqueous extract can result in similar yield to that obtained by for spraying chemicals on a weekly basis.

7. Reduced use of synthetic insecticides without compromising the resulting yields is a novel insect pest control tactic, and reduces possible human health hazards and environmental damage.

8. The spray frequency of chemical insecticides could be reduced by half without losing quantity and quality of the expected crop.

9. It is tentatively concluded that the mode of action of *Capsicum* freeze-dried fruit extract on *P. xylostella* larvae is through repellent and antifeedant action, which leads to larval starvation and death.

10. LD_{50} (lethal dose that can kill 50% of DBM population) of Pure chilli extract is 333.077 g/l

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Appendices

Annex 1: Indigenous Knowledge Assessment; Focus group discussion questionnaire

Questionnaire for Indigenous Knowledge Assessment for the control of insect pests of brassicas using botanicals

Confidentiality will be assured

Date:

A	**Background information**
1.	General
1.1	Name of the group
1.2	Location Covered by the Group
1.3	Number of farmers in the group
1.4	What is the female ratio to male in this group
1.5	Groups decision making procedure
2	Crop
2.1	Does the group grow Kale and cabbage Yes ☐ No ☐
B	Current initiatives in insect pest management
1	Techniques for insect pest management used
1.1	How does the group know that the economic threshold and economic injury level of the insect pests of brassicas.
1.2	Which of the following of the pest management practices that the group use currently in controlling Kale and Cabbage insect pests:
1.2.1	Improved agronomic practices: ☐

1.2.2 Host plant resistance:	☐
1.2.3 Chemical pesticides:	☐
1.2.4 Mechanical practices:	☐
1.2.5 Biological control methods:	☐
1.2.6 Botanicals pesticides:	☐
1.2.7 Others (e.g. behavioural control):	

C

Why are the farmers using what they are using in insect pest control?

D

Why are the farmers not using what they are not using in insect pest control?

E

Group's experience in using botanicals i.e. chilli and marigold and their availability

F

In your views what are problems or illness can chemical insecticides cause

Annex 2: Indigenous Knowledge Assessment; Individual farmer interview questionnaire

Questionnaire for Indigenous Knowledge Assessment for the control of insect pests of brassicas using botanicals

Confidentiality will be assured

Name of the Farmer:		**Date**
District: Location: Type of farming:		
Q1. Do you use botanical farming: Yes ☐ No ☐		
1.1 If no why not		
Q2. Do you use botanical pesticides i.e. chillies and Marigold: Yes ☐ No ☐		
2.1 If no why not		
Comparison of botanical insecticides (chilli and marigold) with chemicals		
I-Price	Botanical	Chemical
Which one is more expensive		
II- Availability		
Which one is more locally available		
III- Safety		
In your opinion which one is safer when applying		
In your opinion which one is safer when storing		
IV-Toxicity		
In your opinion which one is toxic for the users		
V- Impact		
Which one does have negative impact to the environment		
Which one does have negative impact to the human health		
VI- Labour intensive		
Which one requires more labour intensive		

VII- Resistance/resurgence		
In your opinion which one can cause nsect resistance and resurgence		
VIII- Biodegradability/residue		
Which one do you think is more biodegradable after sprayed		
In your opinion which one leaves more residue in and on the soil		
IX- Knockdown capacity (Killing insect)		
Which one do you think has more capacity to kill insects of brassicas		
In your opinion which one does not kill the beneficial insects like bees		
X- Farmers knowledge in using		
Which one do you know better when mixing and spraying		
XI- Legality		
In your opinion which one requires approval from the government for its legitimate use		

Comments: