THE RELATIVE IMPORTANCE OF THREE CABBAGE APHID SPECIES (Brevicoryne brassicae, Lipaphis erysimi; Myzus persicae) AND THEIR PARASITOID COMPLEX IN KENYA.

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ABSTRACT

Studies on the relative importance of the three known species of cabbage aphids (*Brevicoryne brassicae* (Linneaus), *Myzus persicae* (Sulz) and *Lipaphis erysimi* (Kaltenbach)) and their parasitoid complex in Kenya were carried out. The studies involved farmers' fields' surveys and interviews and also field experiments conducted at the Jomo Kenyatta University of Agriculture and technology (JKUAT) Research and Production Department land and in a farmer's field at Limuru. Gloria F1 hybrid was sown at JKUAT while Copenhagen Market variety was sown at Limuru.

The field experiments were conducted in a Completely Randomized Block Design (CRBD) involving three treatments and a control, with three replicates each. The treatments comprised of applications of: - Lambda-Cyhalothrin (Karate; *Bacillus thuringiensis* Berliner (Bt.) var. Kurstaki toxin (Dipel 2x) that selectively kills Diamondback moth (DBM); A combination of the two pesticides (Karate and Bt.) and Untreated controls. Parameters included; relative abundance of the three species of aphids; their corresponding damage to cabbage; the number of mummies per sample; percent parasitism and the proportions of the primary- and hyper-parasitoids hatched. The parasitoid complex was constructed from the identified parasitoids.

The results showed aphid counts to be higher in non karate-treated plots than in the karate-treated ones. More hyperparasitoids notably *Alloxysta sp and Pachyneuron sp.* than the only primary parasitoid (*Diaeratiella rapae*) emerged from non karate-treated plots. This might suggest that karate might have the advantage of repelling hyperparasitoids or inhibiting their emergence. Yield showed some negative correlation with aphid infestations. A combined treatment gave the best overall yield at both sites.

CHAPTER 1: INTRODUCTION

1.1 General Introduction

Aphids have fascinated and frustrated man for a very long time. This is mainly because of their intricate life style in close association with their host plants their polymorphism and ability to reproduce both asexually and sexually.

Unfortunately, there are few biological studies on aphids indigenous to Africa, South America and India. Until such gaps in our knowledge are filled, an account of aphid ecology will be unbalanced because it is based mainly on information about temperate-region aphids. Although predominantly in temperate regions, aphids have a worldwide distribution. Certain species can become very abundant but there are surprisingly few species, especially in the tropics (Dixon, 1985).

About 4,000 species of aphids have so far been described and most of these come from the temperate regions of the world. In the tropics and subtropics family Aleyrodidae and subfamily Coccoidea seem to replace the aphids. The respective distribution of all three groups is assumed to reflect their ability to survive in the physical conditions that prevail in the temperate and tropical regions (Bodenheimer and Swirski, 1957 cited in Dixon (1985)). However, aphids associated with crops have often retained their pest status when introduced from the temperate region into tropical and subtropical regions of the world (Dixon, 1985).

Aphids are serious pests of agricultural crops and forest trees (Dixon, 1973). Aphids affect plants by sucking sap and with large colonies feeding this may lead to stunting of the plant and severe distortion of leaves (plate 1)

1.2 OBJECTIVES

The general objective of this project was to assess the relative importance of the three species of cabbage aphids *(Brevicoryne brassicae, Myzus persicae and Lipaphis erysimi)* and work out their parasitoid complex in Kenya.

1.2.1 Specific objectives

To arrive at the general objective the following specific objectives were pursued:

1 Assessing the relative abundance of the three species of cabbage aphids and the magnitude of their problem.

2. Assessment of the damage and yield loss caused by cabbage aphids in the absence of other major cabbage pests and the effect of various treatments on the natural enemies of aphids – especially parasitoids

3 Identification of the parasitoids of cabbage aphids and evaluating their role in suppressing the population of the aphids

4 Give recommendations that would contribute to the development of IPM (Integrated Pest Management) strategies for cabbage aphids' control.

1.3 Literature review

In 1985 Dixon reported that plants have evolved chemical and physical defenses that operate at different stages of the aphids' host selection process. Certain aphids can modify plant metabolism and development to their own advantage.

Individual aphids are capable of defending themselves against a wide range of natural enemies, with varying degrees of success (Dixon, 1985). Depending on the relative size of the attacking parasite or predator, an aphid will attempt to walk away, drop off the plant or smear the wax it can exude from its siphunculi over an attacker (Dixon, 1958). Waxing the attacker is often accompanied by the release of an alarm pheromone that alerts nearby aphids. There are several alarm pheromones that are released by aphids (Dixon, 1985). The most widespread interspecifically is trans-β-farnescene (Pickett and Griffiths, 1980).

The worldwide known species of cabbage aphids are *Brevicoryne brassicae, Myzus persicae* and *Lipaphis erysimi.*'Mealy cabbage aphid'. *Brevicoryne brassicae* (L) (plate 2) is a green species with a considerable amount of gray; waxy "bloom" on the surface, which gives heavily infested plants a white appearance.

Apterous parthenogenetic females are oval grayish to greenish, covered with mealy secretion. Length of about 2-2.4 mm; head and eyes blackish; antennae about half as long as the body, 3^{rd} antennal segment longer than 4^{th} and 5^{th} together. Legs dark-brown to black, tails long and slender. Abdomen has transversal, dark sclerites on the dorsal side. Cornicles are short, stout and brown; cauda black (Schmutterer, 1969).

Alate, parthenogenetic females are elongate, oval, green, covered with waxy secretion. The length of the body is 2-2.4 mm. Head and thorax dark, Antennae 2/3 or about as long as the body. Legs dark-brown. Abdomen has brown to black transverse, dorsal sclerites. Cornicles are short and stout. Wings hyaline (Schmutterer, 1969).

The cabbage aphid, *Brevicoryne brassicae* is a cosmopolitan pest widely distributed in East Africa (Bahana and Karuhize, 1986). Initially it would have seemed to be primarily an insect of the temperate regions, but has now extended its range to the tropics. It is now found in most of East Africa and in the western part of tropical South America (Schmutterer, 1969).

B.brasssicae is a specialist aphid and feeds on cruciferous plants rich in sinigrin and has an enzyme in its tissue (glucosinolase) capable of detoxifying this highly toxic substance (MacGibbon, 1975; MacGibbon and Beuzenberg, 1978 in Dixon (1978)). Cabbage aphid usually colonizes cole crops; prefer the youngest leaves and flowering parts of broccoli and cauliflower; and underneath cap leaves of cabbage heads.

The mealy cabbage aphid appears to be confined to the cruciferae and is a vector of a number of virus diseases. It is best known as a vector of a mosaic disease that causes pronounced stunting of the plants. The virus is the non-persistent type, transmission can take place after two to three minutes feeding on an infected plant, and the ability to transmit is lost after two hours. Nymphs and adults remove plant sap, causing distortion, stunting, curling, and wilting and often death of the plants (Ralph & William, 1987, in Dixon (1985)).

Under heavy infestation, plants show symptoms of yellowing, curling of leaves and stunted growth (Bahana and Karuhize, 1986). Consequently, infected cabbage does not develop a marketable head (Schmutterer 1968 in Bahana & Karuhize, (1986)).

If aphid infestation occurs early in the plant's development, the yield potential is considerably reduced (Bohlen, 1978 in Bahana & Kuruhize, (1986)). These attacks are worsened by dry weather conditions. B. *brassicea* has also been reported to be a vector of at least 23 viruses within cruciferae (Hill, 1975 in Bahana & Karuhize, (1986)).

In tropical regions the aphid reproduces parthenogenetically throughout the year but in temperate regions sexual forms appear the male being winged and the female apterous(Schmutterer, 1969).

Myzus persicae (Sulz) -'Green peach aphid' is rather slender in form, light green or yellow with indefinite darker stripes on the abdomen (Plate 3). It is world wide in distribution, and is a vector of over 50 virus diseases and has a host range of over 875 species of plants. Aphid feeding causes curled, stunted distorted leaves that become contaminated with cast moult skins, honeydew and sooty mould fungus. In the tropics, all generations may be parthenogenetic. Damage to the blossoms, leaves and fruits of peach trees is rarely serious from these sap-feeding insects, but at times tobacco and garden crops are severely injured.

In Nigeria, it has been found mostly on brassicas in the wet season. *M. persicae* is probably the most polyphagous of all aphids. This aphid has a marked preference for highly nutritious plants (Emden and Bashford, 1971 cited in Eastop and Emden (1972)) perhaps because the small quantities of toxicants ingested when aphids feed on tissues rich in nutrients may be quickly detoxified.

Green peach aphid tends to be spread uniformly on the underside of older leaves in lettuce and cole crops. They rapidly spread to younger leaves and heads when populations increase. In spinach, they colonize all plant parts including the terminal growth.

Lipaphis erysimi (Kaltenbach) –'Turnip aphid' belongs to subfamily Myzinae. It is also known as the false cabbage aphid and has been found on crucifers such as raddish. This species is found in nearly all-tropical regions of the world and may cause similar injury to cabbage as the cabbage aphid *Brevicoryne brassicae.* The false cabbage aphid is an important virus-vector on crucifers in other countries (Schmutterer, 1969). They are leaf-curling aphids occurring in steppe habitats (Stary, 1970).

In East Africa, control of cabbage aphids through pesticide application is practiced mainly on commercial farms, but in majority of cases, particularly on small farm holdings there are no control measures and pest infestation grows unchecked (Amon, 1977 in Bahana & Karuhize (1986)).

Systemic insecticides such as Dimecron, Dimethanoate, Disulfolton and Carbofuran were the main ones in 1970s (Amon, 1977 in Bahana & Karuhize (1986)). In small non-commercial plots chemical control is very uneconomical. The role of natural enemies in the regulation of cabbage aphids in Kenya has not yet been widely understood.

Control operations include burying crop remnants of the previous seasons to destroy all stages of the aphids; using insect-free transplants and applying a pesticide only when necessary and before the leaves become cupped and distorted (Dixon, 1978).

There are various natural enemies of cabbage aphids, notably parasites and predators. Aphid parasites mainly belong to the family Aphidiidae, whereas predators belong to two major subfamilies of the Coccinellidae and Syrphidae. Groups of organisms with atleast one species predatory on aphids include: - *Coleoptera* (eg. *Coccinellidae*), *Diptera* (eg. *Syrphidae*), *Hymenoptera* (eg *Vespidae*), Neuroptera, Heteroptera, Acari and Aves (Frazer 1988).

The Aphidiidae are tiny, Inchneumonoid hymenopterous insects, with an adult size ranging from about one to several millimetres. The coloration of adults is predominantly black or dark brown, with more or less yellowish, orange or yellow-brownish patterns. They strictly are specific solitary endophagous parasitoids of aphids (Stary', 1988). The most common genera are *Diaeretiella* Stary', *Aphidius* Nees, *Lysiphlebus* Forster and *Proan* Haliday among others.

The Aphidiidae generally have four larval instars although different numbers have also been reported. Before completing its development, the larva spins a cocoon inside or under the empty aphid skin. During the development of the parasitoid, the aphid swells and the skin hardens to form the typical "mummy" (Stary', 1988). Prepupal, pupal and adult stages develop within the mummy (Coushman and King, 1977 in Stary' (1988)).

The adults emerge through the emergence hole, which bears an easily broken emergency lid and is circular. This hole can be in any part of the aphids' abdomen with most aphidiid, but some species make the hole in the apical part of the abdomen (Stary, 1974 in Stary (1988)).

Adults are highly active on warm, sunny days, mainly in the late morning hours and in the afternoon. The sex ratio in the field slightly favors the females and reproduction is mainly biparental (Stary, 1988) – with unfertilized (haploid) eggs giving rise to males (= arrhenotoky) and fertilized (diploid) eggs producing females.

Different developmental stages of parasites injure their aphid hosts in the following ways: -

- Adult female parasites cause direct injury by piercing the host cuticle with their ovipositors and an indirect injury by depositing eggs into the host's body cavity.

- The egg of the parasite obtains the necessary nutritive substances osmotically. Unhatched eggs exert a juvenilizing effect on the host, producing metathetely (Johnson, 1959).

- Larval instars I-III feed osmotically and the newly hatched parasite larva diffuses some cytolytic secretion into the host's haemolymph visibly affecting the young embryos and ova of the host. An aphid is killed even if the larva is unable to complete the development inside a certain host (Schlinger & Hall 1960, in Stary (1970))

- Prepupa and pupa occur inside the dead mummified aphids and can therefore not influence the host during its (host's) life.

In general, this injury on host aphids by their parasites influences them in such diverse way as: -

Retarded development, delayed development, the aphids die and become mummified, reduced or inhibited reproduction etc depending on host instar attacked. Tardieux and Rabasse (1990) studied the role of some epigenentic factors influencing the host suitability of *Myzus persicae* for the parasitoid *Aphidus colemani.* They listed four commonly observed host responses that are also common in other aphid-aphidiid associations.

These host responses were: -

1. A host develops into a mummy
2. It dies very soon after being stung
3. It develops/manifests a cellular 'immune' response
4. It shows no apparent perturbation subsequent to the sting

Ralph and William (1987) reported 94% parasitism of *Myzus persicae* and related hosts on cabbage by *D. rapae* (Dixon, 1985). *Brevicoryne brassicae* (L) is also attacked by *Praon volucre* (Haliday), *Aphidius picipes* (Nees) attacks *M persicae* whereas *Lipaphis erysimi* (Kaltenbach) is attacked by *Lysaphidus erysimi* (Stary') (Stary", 1970).

Most parasites, with a host range including several species, show some preference for one of the host species. Host preference can be influenced by a number of factors such as: - lack of hosts in a given habitat, occurrence of a sustainable and less suitable hosts in a colony, similarity of host ecology, geographical factors and host plant (Sekar, 1957).

Pimentel (1961) studied *Diaeretiella rapae* and its relation to *Brevicoryne brassicae, Lipaphis pseudobrassicae* and *Myzus persicae* on Brassicae plants. He observed a difference in the preference of one species for another. Density searching relationship is however believed to play a role: Whereby if *D. rapae* is given an equal choice, it might prefer one aphid to another, but when one aphid species is abundant, opportunity for contact is increased so that the most abundant species is the most parasitized (Stary, 1970). The preference of *D.rapae* for *Brevicoryne brassicae* is however well documented.

In general, the ovipositing female can distinguish an already parasitised aphid to a certain degree; therefore avoiding superparasitism (Stary, 1988) but Broussal (1966,in Stary, (1970).) has reported the inability of *D.rapae* to recognize already parasitised aphids in the case that they contained only parasite embryos

Ovipositing females do not prefer higher instars of their host and any 'distinguishing' between parasitised and non-parasitised aphids is due to host instar preference.

Generally, parasites show good adaptation to certain behaviors that are exhibited by the aphids when tapped by the female parasite antennae. These behavior include: - some aphids remain quite, others species move their legs or antennae slightly, others move their legs very strongly, pull their rostrum out of the plant and fall off the plant. A different response by the aphid discourages the parasite and breaks off its oviposition attempts.

Some aphids have a dense wax cover on their bodies. Parasites that are well specialized in their oviposition behavior avoid contact with this wax cover as they could severely injure themselves. George (1957) observed that *D.rapae*, a parasite typical of some wax producing aphids such as *Brevicoryne brassicae* restricts its attacks to those host individuals which are at the edges of the colony where the wax cover is not very developed.
Mummified aphids are easily found and distinguished among the other aphids in a colony as they have a different color. *B brassicae* attacked by *D rapae* changes to yellowish to white-yellowish mummies. Cocoons are whitish for *Praon volucre* parasitisation (Stary 1970). *M.persicae* is parasited by *Aphidius picipes* (Nees) forming yellow mummies whereas *L.erysimi* is attached by *Lisaphidus erysimi* (Stary') and mummified aphids are yellow in colour (Stary, 1970).

In studies carried out on spring greens (kale) to determine the primary parasitoids and hyperparasitoids of mummies of *Brevicoryne brassicae* Souza *et al* (1992) found *Diaeretiella rapae* as the only primary parasitoid. Bahana and Karuhize (1986) made a similar observation in Kenya in their studies on the role of *D rapae* in the population control of cabbage aphids.

Sauza *et al* (1992) found *Alloxysta brassicae* (A Victrix), *Pachyneuron aphidis* and *Asaphes lucens* to be among the main hyperparasitoids of *D.rapae*. Hyperparasites of genus *Alloxysta* (= *Charips*) in the Cynipidae are endoparasitic. The female deposits her egg inside the primary parasite larva while it is developing in the live aphid before it is mummified (Daniel & Sullivan, 1988). The hyperparasitic larva feeds internally on the primary host.

Under laboratory conditions, the dead aphid is mummified approximately 8 days after being parasitized by the primary parasite and only then does eclosion of the *Alloxysta* larva from the egg occur inside the primary parasite larva (Daniel & Sullivan, 1988). Following this, further development of the primary larva is terminated and it never emerges as an adult.

The *Alloxysta* completes its feeding externally on the remains of the primary larva, inside the aphid mummy, after emergence from the primary larva. It then cuts a jagged 'exit hole' in the dorsum of the mummy emerging as an adult. The time from oviposition by the female *Alloxysta* to subsequent emergence of her offspring as an adult is between 13 and 20 days (Daniel & Sullivan, 1988).

Pachyneoron and *Asaphes* (Pteromalids) are ectoparasitic hyperparasites and are not host-specific as opposed to *Alloxysta.* Daniel and Sullivan (1988) have reported a strong phenological synchronization between the endoparasitic hyperparasite (*Alloxysta* = *Charips*) and the primary parasite *(Diaeretiella)*.

This synchronization is attributed to hormonal cues by the primary host that influences the hyperparasite. Such synchronization does not exist between the ectoparasitic hyperparasites (*Pachyneuron* and *Asaphes*) and the primary host (*Dieretiella)* in the cabbage aphid complex.

The number of aphidophagous species found in crops depends on location, agronomic history and crop characteristics. Annually planted crops tend to have fewer species than more permanent crops. Coccinellids are the most common predators of aphids. They belong to the coleopterous superfamily Cucujoidea, section Clavicornia (Frazer, 1988). Important aphidophagous genera include *Cheilomenia* and *Hippodamia.*

The Diamondback Moth (DBM), *Plutella xylostella* (L) was first recorded as an important pest of cabbage in 1746 (Harcourt, 1963 in Idris & Grafius (1993)). It is a worldwide pest of brassica crops.

Diamondback moth (*Plutella xylostella*) is the major (key) pest of brassicas (kale, cabbages etc) in many countries, including Kenya (Mwaniki *et al*, 1998). The microbial insecticide *Bacillus thuringiensis* (Bt) Berliner Var. *Kurstaki* has been used but Tabashnik *et al* (1990) reported resistance to this pesticide also.

Natural enemies are able to hold DBM below economic thresholds in some regions, despite its wide adaptability to new environments and insecticides (Idris and Grafius, 1993).

Cabbages and kale are the major vegetables consumed in Kenya. A report given by KARI in 1995 indicated that the major constraints in the vegetable farming identified during the 1991 priority setting exercise were: - Low yielding varieties and susceptibility to Black Rot disease and Diamondback Moth (DBM).

Poor marketing margins, price fluctuations, and lack of irrigation facilities, poor infrastructure and post-harvest losses have been identified as the paramount non-technical problems that affect domestic production of vegetable. The latter two also affect export of vegetables as do other problems like inadequate cargo capacity and competition from other countries especially India, South Africa, Israel and Zimbabwe.

The common technical problems include lack of basic seeds, adapted varieties, inappropriate agronomic packages, diseases, poor post-harvest handling practices and insect pests.

Farmers' fields surveys and interviews confirmed past findings, widely quoted in literature that insect pests and diseases are the major technical constraints to cabbage, and in general, horticultural production.

CHAPTER 2: MATERIALS AND METHODS

2.1 Field surveys, study areas and experiment sites

Preliminary field surveys were carried out in mid-August, 1999, in the Limuru-Kinangop and Thika-Murang'a zones that are known for the production of cabbage, kale and other brassicas. These surveys were devoted to selection of sampling sites, field trials sites selection, orientation and overall reconnaissance of the study areas.

Out of these surveys (and also for logistic purposes) Ndeiya in Limuru Division and Jomo Kenyatta University of Agriculture and Technology (JKUAT) were selected as suitable field study sites.

2.1.1 Description of Study Areas

Ndeiya location is in Limuru division, Kiambu district about 55 km west of Nairobi. It is in the lower highland agro ecological zone lying between 1980 and 2280 meters above sea level (m.a.s.l). It has the Rift Valley escarpment as its western border and the mean annual rainfall is between 900-1200 mm whereas the mean annual temperature is between 15.2 and 17.6^0 C.

The farms are located on gentle slopes. Cabbage and other brassicae are watered with cans when rainfall is scarce. Studies showed that potato, tomato, pyrethrum, maize and nappier grass are also widely grown in this area.

The JKUAT study site is located near Thika town 1500 m.a.s.l (About 20 km from Nairobi) in Thika district. The area is lowland and this together with the soil type encourages serious flooding when rainfall is high. The trial site was part of the University land that is set apart for research and development, and managed by the farm department. Plantation farms including those for export flowers; pineapples, coffee and Kenya Agricultural Research Institute (KARI) – horticultural division, dominate the Thika zone. Other farmers do small-scale farming in the neighborhoods, their major crops being maize, beans and brassicas. Both study areas have the long and short rain seasons during which brassicas are widely grown.

2.1.2 Establishment of field experimental sites

The Limuru field experiment site was established at the end of August 1999, in a farmer's field. It measured 30m by 20m ($600m^2$) and was demarcated into twelve plots, each of which measured 5.85m by 6.6m.

A 0.5m path was left around each plot *(Fig 2.1)*. Copenhagen Market variety was transplanted to the Limuru site. The spacing requirements were 60cm between rows and 45cm between plants. Each plot had ten rows of twelve plants each, giving a total of 120 plants per plot.

The other site was located at JKUAT research farm. It measured 22m by 22m ($484\ m^2$) and was demarcated into twelve plots each measuring 6.6m by 6.6m. Similarly a 0.5m path was left around each sell. (Fig 2.2)

The size of each plot at both sites was calculated in accordance with the spacing required for the variety to be planted and the total number of cabbage plants required. Gloria F1 Hybrid was grown at JKUAT and required a spacing of 60 by 60 cm. Each cell was designed to hold ten rows each with ten plants giving a total of 100 plants per plot.

ACTUAL SITE PLANS

Figure 3.1: Limuru Site Plan

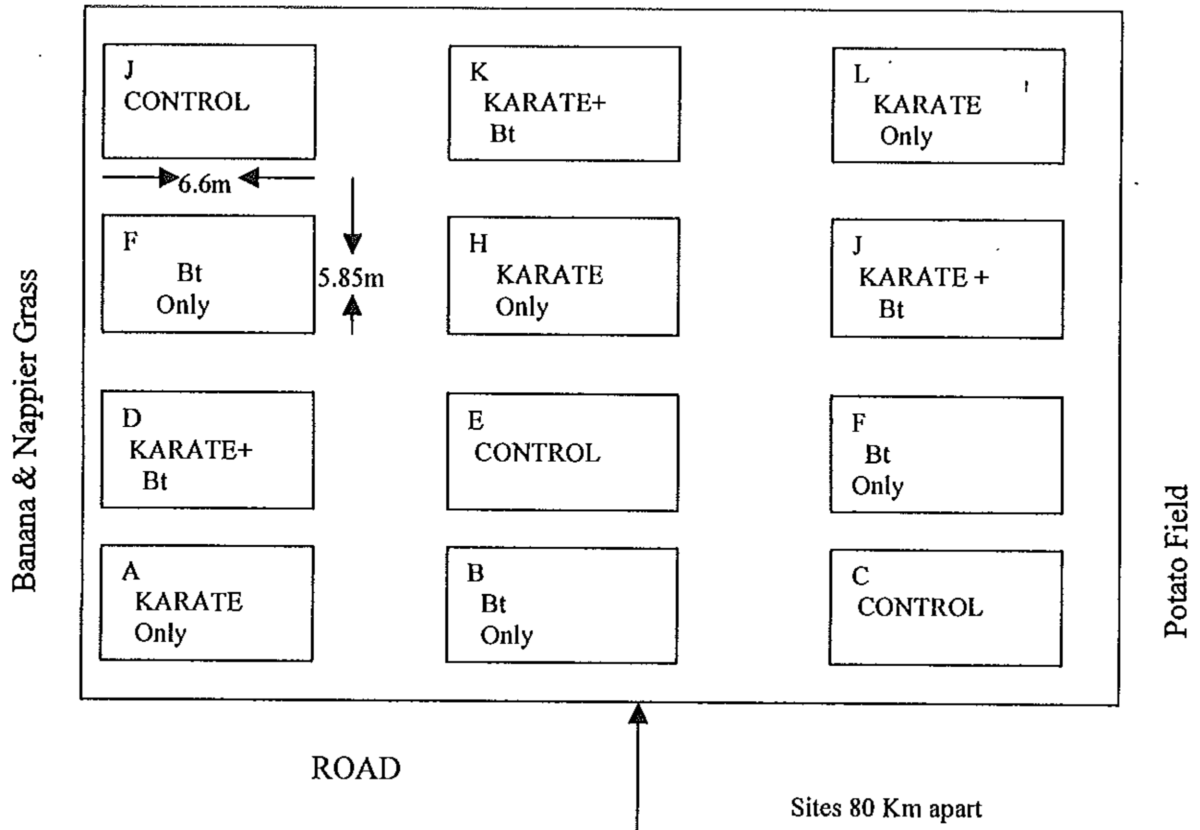
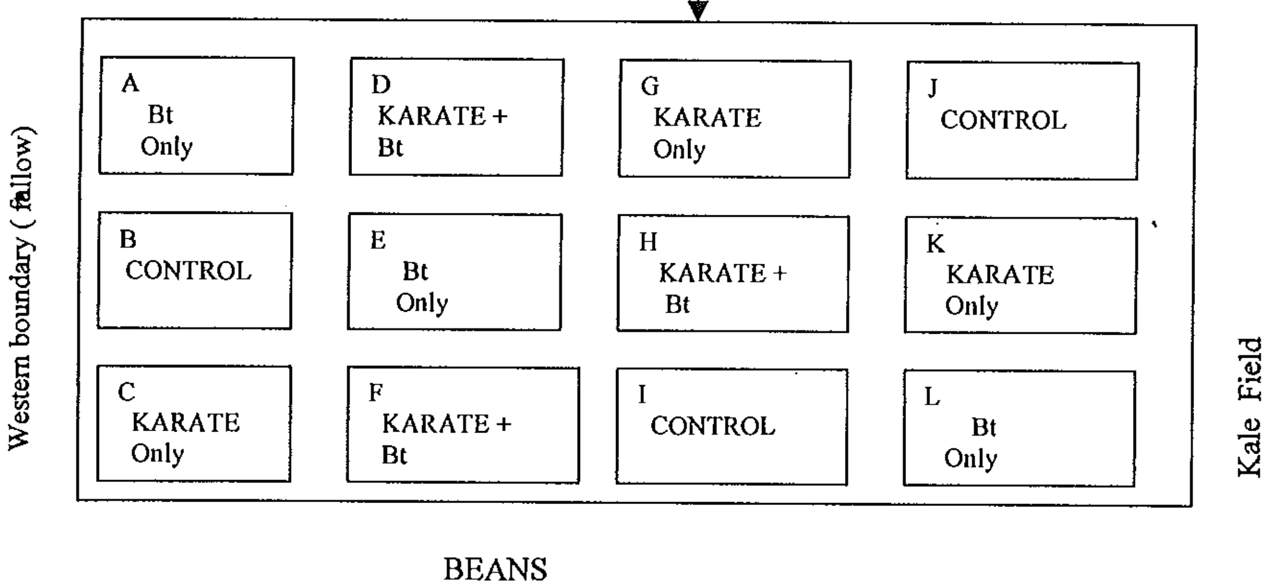


Figure 3.2: JKUAT site plan



The twelve units at each site comprised of four treatments (randomly allocated-completely randomized block design - CRBD), each with three replicates.

2.2 Cabbage varieties and seedlings

Two varieties of *Brassica oleracea capitata* (cabbage) were planted at the two field sites. The cabbage seeds used were obtained from the Kenya Seed Company Limited (Trade name Simlaw seeds) and are recommended for tropical conditions. The Gloria F1 Hybrid seeds were of 99% purity, germ 90% and treated with Thiram.

2.2.1 Preparation of seedlings

Compost manure was sieved into twelve trays using a fine wire-mesh sieve. Each cabbage variety (Gloria F1 Hybrid and Copenhagen market) was sown into six trays at the beginning of September 1999. The trays were placed on a bench in a screen house (greenhouse) and watered daily using a 250ml plastic cup perforated at the bottom. Contingency seedlings were sown on other trays.

More compost manure was sieved into planting bags and the seedlings transferred into individual planting bags about three weeks from the sowing date. The seedlings in bags were kept in a warmer screen house and given a standard treatment with carbamate to prevent Diamondback moth attacks. Early in October (about 5 weeks post-sowing) the seedlings were taken out of the screen house to the open in order to harden. Regular watering was done throughout this period, the amount and frequency being gradually reduced to allow hardening.

2.2.2 Transplanting

In mid-October, the seedlings were transplanted into the field sites. At transplanting Di-ammonium Phosphate (DAP) was applied at the rate of 200g per hill (KARI, 1996). Top-dressing with Calcium Ammonium Nitrate (CAN) was thumb and forefinger and slowly turning it until the entire underside of the leaf becomes visible (Heathcote, 1972). Where a leaf had more than 50 aphids it was cut carefully and taken to the laboratory for more accurate counting of the aphids.

For each plot two sets of ten samples were taken from pre-determined random plants. One set was used to assess percentage parasitization of the aphids and also to work out the aphid-parasitoid complex. The other set was used to quantify aphid populations per species and the damage levels. The DBM infestations were assessed using all the 20 samples in each plot. All the data were recorded in appropriate datasheets.

In cultivated (farmers') cabbage fields samples were taken from the central parts of the field and from the edges to cover the ecotone problem (Stary, 1970). To ensure that sampling was free from bias a fixed number of paces (3-5) were made diagonally across the field before taking the nearest cabbage plant, randomly selected. A sample of 20 plants in each quadrant of a field was taken (Stary, 1970) care being taken to minimize disturbance and loss of aphids in the leaves.

2.4.2 Assessment of the relative abundance of the three species of cabbage aphids

Levels of infestation by each of the three species of cabbage aphids were estimated using the 'three leaf' method. A random sample of ten plants was taken per plot. Aphid populations were quantified using a scale of:

0	Aphids	score 1
1-10	"	score 2
11-50	"	score 3
51-100	"	score 4
>100	"	score 5

Damage due to aphids' attack was also quantified using the following scores:

0	No damage	- score 1
1-10%-	Slight damage	- score 2
11-25%	Moderate damage	- score 3
26-50%	Heavy damage	- score 4
51-100%	Severe damage	- score 5

NB: A given score was awarded depending on the leaf area damaged due to aphids feeding. If there was no damage at all a score of one was awarded, if a tenth of the leaf had been damaged a score of two was given etc. The scores (i.e. 1 unto 5) used to quantify aphid populations and also damage are non-parametric and were treated that way during analysis of the data whereby Spearman's Rank Order correlation analysis was done.

The infestation levels of DBM were quantified by counting the 3rd and 4th instar larvae on the entire plant. An average of two 3rd and/or-4th instar larvae per plant warranted treatment with *Bt* against the DBM (Brunner & Stevens, 1986).

Samples were taken at weekly intervals from the third week after transplanting to the time of harvesting. The average score for infestations for each aphid species and for damage were computed for each week.

2.5 Percentage parasitism and 'parasitoid complex' studies

Intensive studies were conducted in order to establish the parasitoid complex and percentage parasitism. This involved the continuous observation of the population of parasitoids in the study sites (Southwood, 1994).

Aphid counts were routinely done on a weekly basis and the number of mummies recorded. The percentage parasitism was then computed from the number of mummies recorded. The parasitoid complex was worked out as described in 2.5.1 and 2.5.2. The proportions of emerged primary and secondary parasitoids were noted. Other natural enemies were also recorded. The percentage parasitism was calculated as a proportion of mummies to the total number of live and parasitised aphids in a sample. The following formula that was developed for this purpose:

$$\%\ \textbf{Parasitism} = [\ \Sigma\textbf{Mummies} \div \Sigma\{\textbf{mummies} + \textbf{live aphids}\}\ \textbf{in sample}] \times \textbf{100.}$$

2.5.1 Rearing of parasitoids in plant samples

Portions of plants with aphid colonies were collected and put in small plastic vials or big plastic bottles. The plant material was sandwiched between strips of filter paper before being placed in the containers. A piece of fine or dense nylon texture, tied with a rubber band was used to cover the plant portion in the container (Stary, 1970).

The parasites and aphids cannot escape through the nylon texture, but have sufficient air. Only small parts of the plants were put in the vials. Each sample was labeled according to the plant number and the plot from which it was collected.

Once brought to the laboratory the material was transferred into more spacious rearing cages or bottles. The material was reared in the laboratory at a room temperature ranging from 23 – 25^{0}c in order to allow the parasites to emerge (Stary, 1970).

2.5.2 Sorting of the hatched parasitoids

The material was regularly inspected for emergence of parasitoids. During analysis the piece of plant would be carefully taken out of the breeding vial and the dead hatched parasites placed on a piece of paper. The parasites were sorted out with the help of a fine plant brush and a binocular-microscope (Heathcote, 1972).

The primary parasites, emerging over 2 days after sampling, and the relative numbers of hyperparasites were recorded for each sampling occasion (Stary, 1964). The aphid parasites were preserved under 70% alcohol in specimen bottles, appropriately labeled, and forwarded to the Biosystematics Support Unit of ICIPE for final identification.

A part of the mummified aphids were left and transferred to smaller vials. Other natural enemies were recorded too. The numbers and level of activity of parasitoids in the different treatments were compared.

2.6 Yield – loss Assessment

The quality and quantity of cabbages produced at each site was assessed in order to establish the pest-yield relationship and appraise losses due to cabbage aphids and DBM.

At harvest quality and quantity reduction of the cabbage heads was evaluated. Assessment of quality involved checking the

- Head weight
- Quantity

Yield was assessed by taking the weight of cabbage heads immediately after harvesting (Walker, 1981). The weight per plant in the treated plots was compared with that for the untreated plots (controls). This was done in order to evaluate the impact of aphids' damage on cabbages (by comparing yields).

2.7 Data analysis

The mean aphid counts and percent parasitism were compared between treatments (each sampling date at a time) using one-way ANOVA at $P<0.05$. The means for aphid counts and % parasitism were also displayed in graphs to show the within-season trend and difference between the treatments. Average weekly scores (ranks) for infestations of *Brevicoryne brassicae, Myzus persicae* and *Lipaphis erysimi* were computed for each treatment. The means of weekly damage scores were similarly computed. The pattern of infestation by each species and also damage are presented graphically for each treatment and for each site. The mean scores for each species were subjected to Spearman's Rank order Correlation analysis against the damage scores for each treatment. The proportions of the primary parasitoid (*D.rapae*) and secondary parasitoids (*Alloxysta sp* and *Pachyneuron sp*) are presented in bar charts.

Weight per plant in the treated plots was compared with that for untreated plots (controls) using one-way ANOVA. SPSS and STATISTICA software were used in these analyses.

CHAPTER 3: RESULTS

3.1 Farmers' fields survey

3.1.1 Land tenureship and land use

The survey on farmers' fields revealed that out of an average 5.78 acres of land per farmer an average 0.936 acres per farmer was under cabbage, showing an average of 16.19% of the total land to be under cabbage. 80% of the interviewed farmers indicated farming to be their only source of income and 95% of all the farmers indicated that cabbage was the most profitable of the crops they grew. Potatoes, maize, beans, pyrethrum and Napier grass (fodder) is also grown.

Gloria F1 hybrid was the most commonly grown cabbage variety followed by Copenhagen Market. Drumhead, sugarloaf, sweet cabbage and others (fig 3.1) are also grown. Gross income from cabbage farming ranged from 40 – 4400 US Dollars depending on the price of one cabbage (which range from 0.04 –0.3 USD. each) in the market in a season.

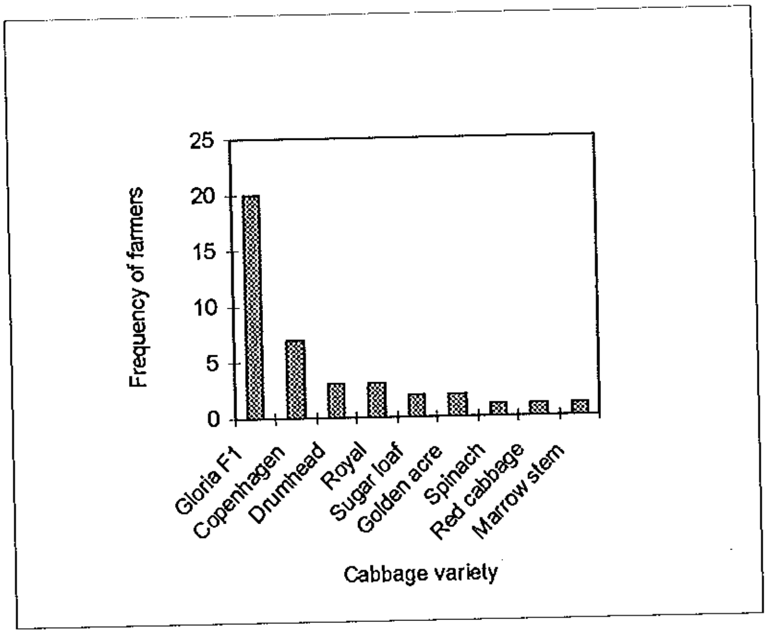


Figure 3.1; Different cabbage varieties grown by farmers

3.1.2 Crop management

All the interviewed farmers buy seeds from the shop and raise their own seedlings in seedbeds. There are two planting cycles per year, which principally begin in the months of April (planting1) and September – October (planting 2). All the farmers watered the seedlings to at least one-week after transplanting and the watering can is mainly used for this purpose.

Most of the farmers practiced crop rotation in their cabbage fields and applied fertilizers and manure. Di-ammonium Phosphate (DAP) was used during transplanting and Calcium Ammonium Nitrate (CAN) was used for top-dressing. Most farmers also applied foliar fertilizers (spray) on their cabbage fields.

The survey showed that Aphids and DBM were the most important problems faced in the cultivation of cabbages. Other problems encountered include cutworms, fungal infections, weeds and drought.

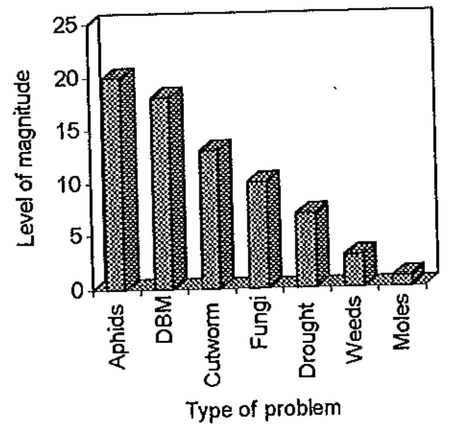


Figure 3.2: Problems faced by cabbage growers in the survey area

3.1.3 Knowledge attitude and practices (KAP) in cabbage pest management

Among the interviewed farmers 91% of them believed that the only means of protecting their cabbage fields from aphid (and other pests) was the use of pesticides. They also believed that they would lose between 25-100% of their crop if they did not use pesticides to combat aphids. However, 95%of them actually used pesticides and only 5% of farmers applied no pesticides at all.

Only 20% of farmers interviewed had an idea of biological control agents such as predators. The same proportion applied cultural methods such as use of concoctions of Mexican marigold and also Neem plant. Of the interviewed farmers, 50% had noticed the presence of other 'strange' insects (predators and parasitoids) in their cabbage fields but they did not know their role in cabbage aphid's control.

The most commonly used pesticide in aphid control was Lambda – Cyhalothrin (Karate) followed by Dimethoate and Brigade. Other pesticides included Ambush, Marathon, M-45 and Diazinon. Farmers also used Ridomil, Acrobat, Milaz and other fungicides on their cabbage fields.

A few farmers added stickers to the pesticides in the mixing tanks. 85% of the farmers correctly mixed the pesticide according to the manufacturer's instructions but the rest either put the amount specified by the seller (shopkeeper) or the amount they thought to be appropriate. One farmer applied ten times more than the recommended amount of Karate.

65% of the farmers applied pesticides in combinations, that is, mixed two or more pesticides together and/or mixed pesticides with fertilizer. The most common combinations were:

- Karate + Brigade + Dimethoate
- Karate + Foliar feed (fertilizer)
- Karate + Ridomil (fungicide)
- Milaz + Diazinon
- Karate + Acrobat (fungicide)

Most of the farmers applied pesticides after observing pest or disease attack but 20% of the farmers used calendar application. The farmers applied pesticides on an average of three times in a single cabbage growing cycle.

Most farmers left an appropriate safety period between the last applications of pesticides and harvesting of the cabbage. However, 15% of the farmers, did not take such necessary precautions with some even applying pesticides 1–3 days before harvesting (especially cabbages meant for urban markets – Limuru or

Nairobi). The farmers spent between 10.67 – 66.67 USD on pesticides in each cabbage cycle.

The farmers use a sprayer (mainly knapsack) for applying the pesticides. Some farmers owned a sprayer while others hired or borrowed one and in case where none was available watering cans were used for pesticide application. The latter case indicates the gravity of the risk of direct poisoning of farmers.

3.2 Populations of aphids in different treatments

The abundance of all the three aphid species on cabbage in each treatment are summarized in appendix 2 and appendix 3. Aphid counts were higher in the plots that were not treated with Karate at both sites. Low aphid counts were recorded in the plots treated with Karate (figs 3.3 and 3.4).

The pattern of aphid abundance was very similar between Bt only and Control plots. In non-karate plots aphid counts were high from the first sampling occasion (3rd week after transplanting) to the fifth sampling occasion (7th week after transplanting). A gradual drop in aphid counts followed this until the cabbage was harvested.

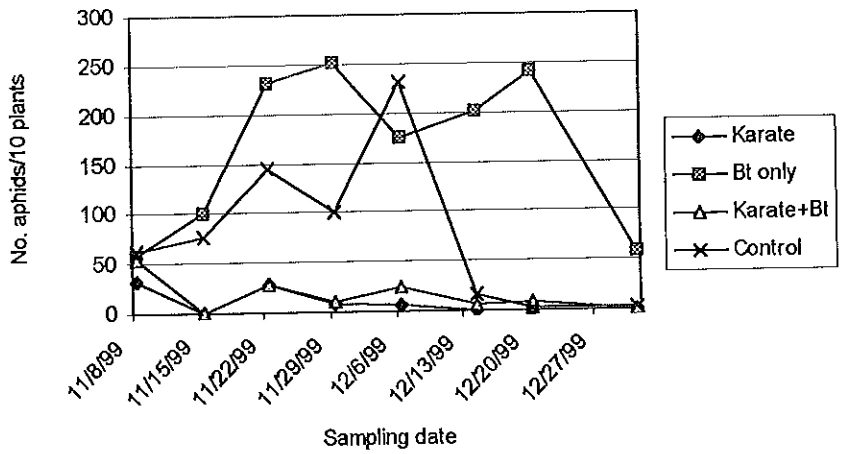


Figure 3.3: The pattern of aphid abundance in different plots at JKUAT

The data used are shown in appendix 2

Aphid counts in karate-treated plots were fairly high during the first sampling date. The counts then sharply dropped and remained low throughout the season. The high aphid counts at the beginning (sampling 1) could be due to the fact that no treatments (application of Karate in these plots) had been done at that time. Aphid counts were evidently higher in the control and Bt-only plots whereas they were very low throughout the season in the karate and Karate + Bt plots. The highest recorded counts were 250 aphids per 10 plants. This was observed in both the control and Bt-only plots. At JKUAT infestations were high in the non-Karate plots (100-250 aphids per 10 plants), in the period from 11th November to 20th December within this season (September- December season i.e. planting 2 on the farmers' calendar).

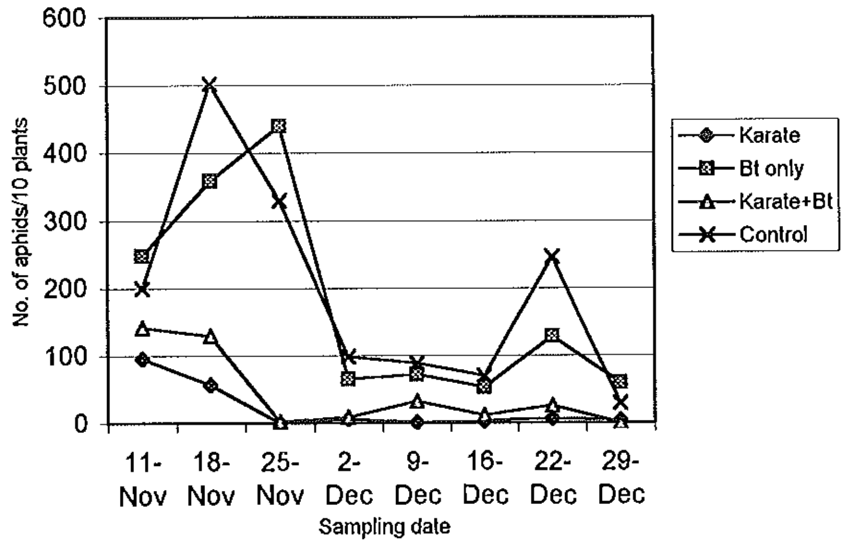


Figure 3.4: The pattern of aphid abundance in different plots at Limuru

The data used are shown in appendix 3

Between December 2nd and 16th there were low aphid (less than 100/10 plants) infestations in all plots. This could be due to the weather, extremely high rainfall, being unfavorable for the aphids even in the non-karate plots. In non-karate plots there were two peak infestation periods in the season: 18th and 25th November (highest peaks, control and Bt plots respectively) and 22nd December (smaller peak in both control and Bt plots).

One-way ANOVA for aphid counts (for each date) between treatments revealed that there were significant differences (at 5% significance level) between treatments in the first five sampling dates. This was especially true from sampling date 2 (4th week after transplanting and period when treatments started) to the fifth sampling date (7th week after transplanting and period when heads were forming, aphid counts falling and treatments stopped). The ANOVA results are given in Table 3.1 and Table 3.2 below).

Table 3.1. Aphid counts ANOVA summary for JKUAT

		Sum of Squares	df	Mean Square	F	p-level
8th Nov	Between Groups	1696.000	3	565.333	.273	.843
	Within Groups	16582.667	8	2072.833		
	Total	18278.667	11			
15th NOv	**Between Groups**	**22701.333**	**3**	**7567.111**	**7.324**	**.011**
	Within Groups	**8265.333**	**8**	**1033.167**		
	Total	**30966.667**	**11**			
22nd Nov	Between Groups	88736.333	3	29578.778	2.936	.099
	Within Groups	80607.333	8	10075.917		
	Total	169343.667	11			
29th Nov	Between Groups	117203.333	3	39067.778	2.372	.146
	Within Groups	131773.333	8	16471.667		
	Total	248976.667	11			
6th Dec	Between Groups	112278.333	3	37426.111	.757	.549
	Within Groups	395529.333	8	49441.167		
	Total	507807.667	11			
14th Dec	Between Groups	85736.250	3	28578.750	1.117	.398
	Within Groups	204722.667	8	25590.333		
	Total	290458.917	11			
20th Dec	Between Groups	126603.000	3	42201.000	1.129	.394
	Within Groups	298936.667	8	37367.083		
	Total	425539.667	11			
31st Dec	Between Groups	7688.333	3	2562.778	1.566	.272
	Within Groups	13091.333	8	1636.417		
	Total	20779.667	11			□

Significant difference is shown in bold: Sampling date 2 (15th November).

Means of aphid counts are shown in appendix 2

Table 3.2. Aphid counts ANOVA summary for Limuru

		Sum of Squares	df	Mean Square	F	p-level
11th Nov	Between Groups	40430.667	3	13476.889	3.669	.063
	Within Groups	29389.333	8	3673.667		
	Total	69820.000	11			
18th Nov.	Between Groups	380578.000	3	126859.333	2.881	.103
	Within Groups	352214.667	8	44026.833		
	Total	732792.667	11			
26th Nov,	**Between Groups**	**461018.250**	**3**	**153672.750**	**5.892**	**.020**
	Within Groups	**208650.667**	**8**	**26081.333**		
	Total	**669668.917**	**11**			
2nd Dec.	Between Groups	18294.917	3	6098.306	2.863	.104
	Within Groups	17039.333	8	2129.917		
	Total	35334.250	11			
9th Dec.	**Between Groups**	**14132.667**	**3**	**4710.889**	**6.416**	**.016**
	Within Groups	**5874.000**	**8**	**734.250**		
	Total	**20006.667**	**11**			
16th Dec.	Between Groups	9431.583	3	3143.861	2.264	.158
	Within Groups	11109.333	8	1388.667		
	Total	20540.917	11			
22nd Dec.	Between Groups	109375.000	3	36458.333	1.158	.384
	Within Groups	251774.000	8	31471.750		
	Total	361149.000	11			
29th Dec	**Between Groups**	**6913.667**	**3**	**2304.556**	**4.914**	**.032**
	Within Groups	**3752.000**	**8**	**469.000**		
	Total	**10665.667**	**11**			

Significant differences are shown in bold: Third, fifth and last (eighth) sampling dates. Aphid counts are shown in appendix 3

From the 7th week after transplanting (14th December) to the 10th week (end of December-harvest time) there was no significant difference (at 5% significance level) in aphid counts at JKUAT. The same was also true for Limuru on 16th December (8th week after transplanting) and 22nd December (9th week – just before harvest). This period of no significant difference in counts coincided with the time when cabbage heads had formed and rainfall was higher than before.

3.3 Relative abundance of three species of cabbage aphids and their relationship to crop damage

Analysis at 5% level of significance revealed that *Brevicoryne brassicae* (L) was the most abundant of the three aphid species in all the treatments and at both sites. *Myzus persicae* and *Lipaphis erysimi* were relatively less abundant and their abundance patterns were similar. In the karate treated plots the average scores were low for the three aphid species as compared to the average scores for non-karate treated plots. At Limuru scores for Karate-only plots ranged from 1.1 to 1.23; the Karate + Bt plots' scores were between 1.15 to 1.75 whereas Bt only plots' scores were between 1.2 to 2.7 and scores for control plots were between 1.2 to 2.55. The average mean score for each species for each treatment are shown in appendix 4.

Spearman's Rank Order correlation analysis at 5% significance level showed that damage scores were closely correlated to those of *B. brassicae* than to the scores for the other two species in all the cases. This implies that *Brevicoryne brassicae* is the most important of the three species with regard to direct crop damage. Patterns of the scores for abundance and damage are shown in the Figures 3.5 to 3.12. Damage was higher in non karate-treated plots (Figs. 3.13 & 3.14).

Data for figures 3.5 to 3.14 are shown in appendix 4.

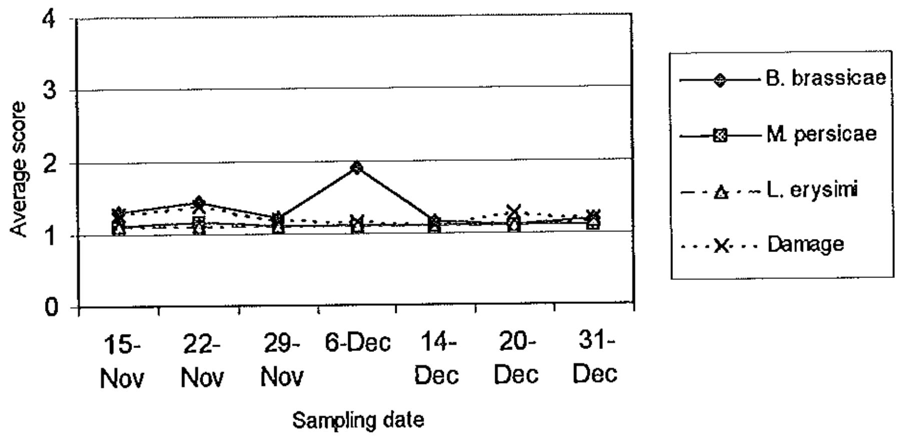


Figure 3.5; Patterns of aphids' and damage scores; Karate only-JKUAT

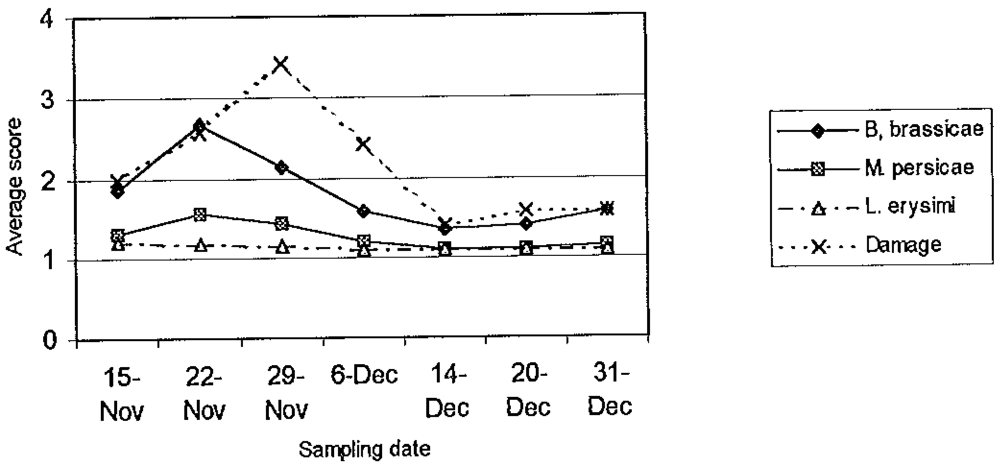


Figure 3.6: Patterns of aphids' and damage scores; Bt only- JKUAT

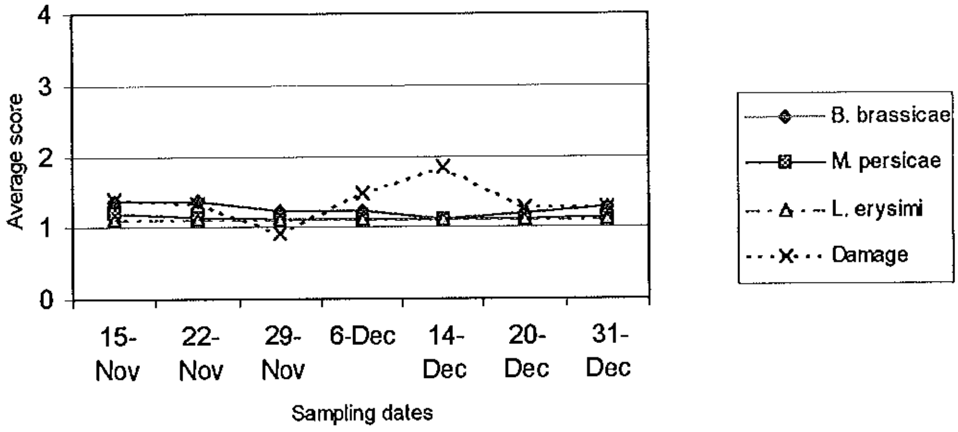


Figure 3.7: Patterns of aphids' and damage scores; Karate + Bt-JKUAT

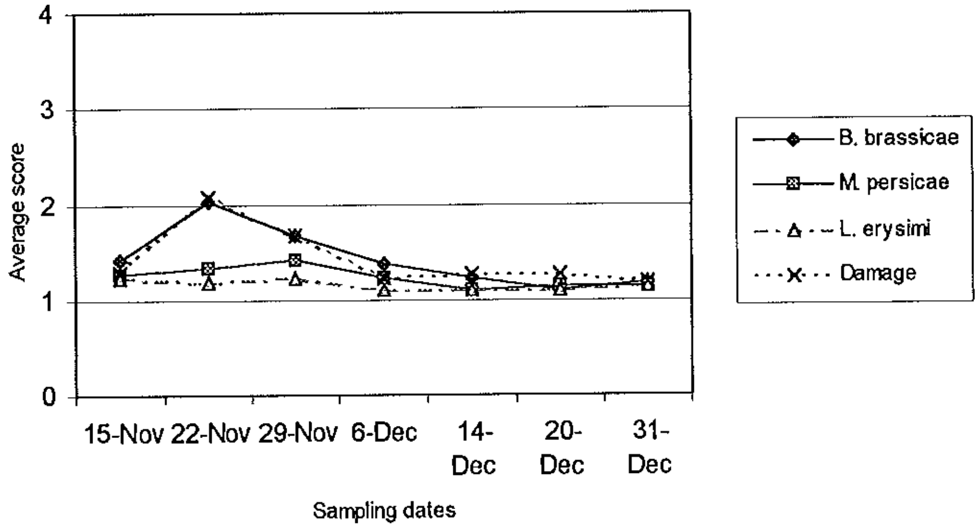


Figure 3.8; Patterns of aphids' and damage scores; Controls JKUAT

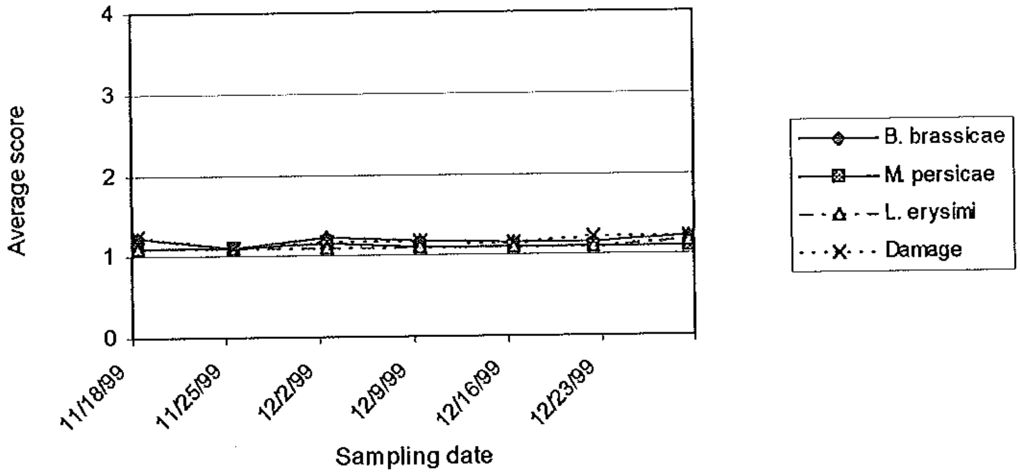


Figure 3.9: Patterns of aphids' and damage scores; Karate only-LIMURU

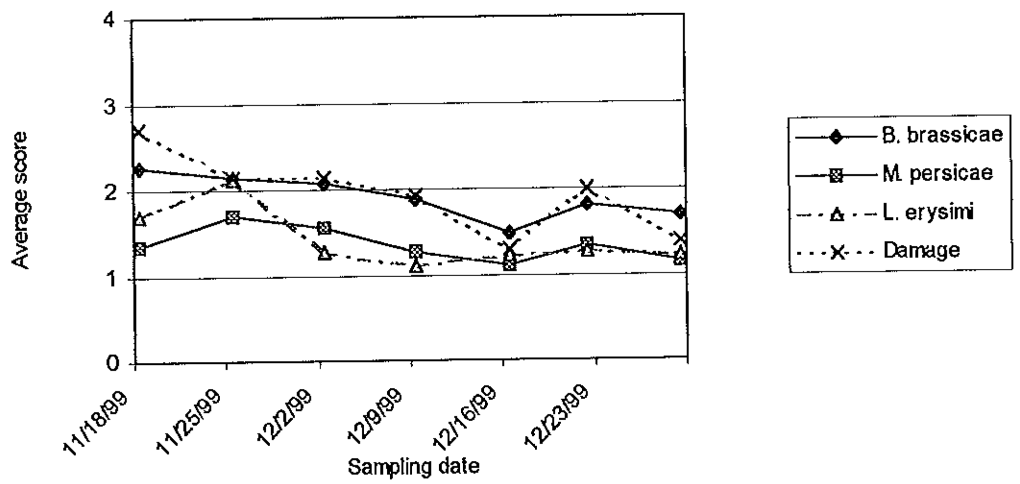


Figure 3.10: Patterns of aphids' and damage scores; Bt only LIMURU

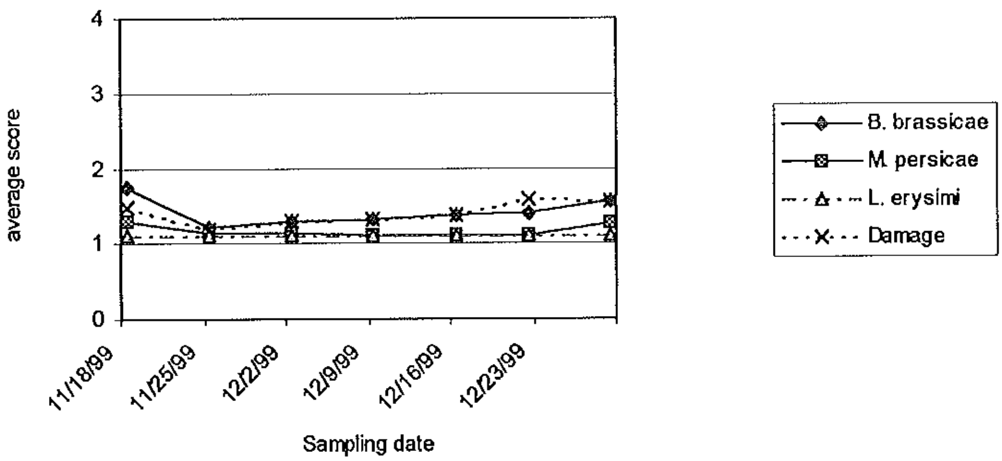


Figure 3.11: Patterns of aphids' and damage scores; Karate + Bt-LIMURU

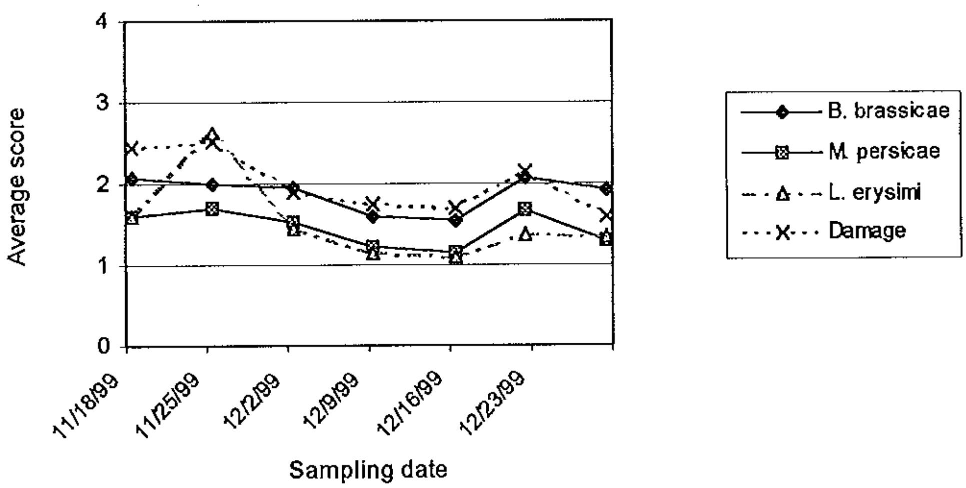


Figure 3.12: Patterns of aphids' and damage scores; Controls-LIMURU

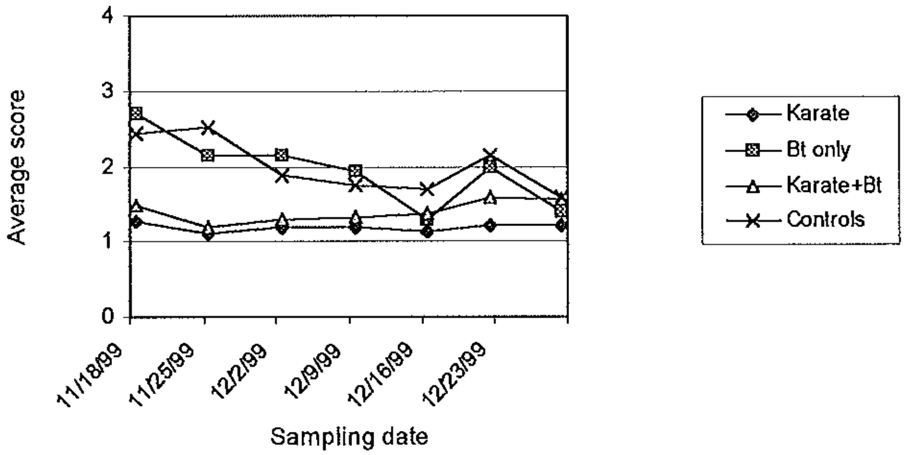


Figure3.13: Pattern of damage in different treatments at Limuru

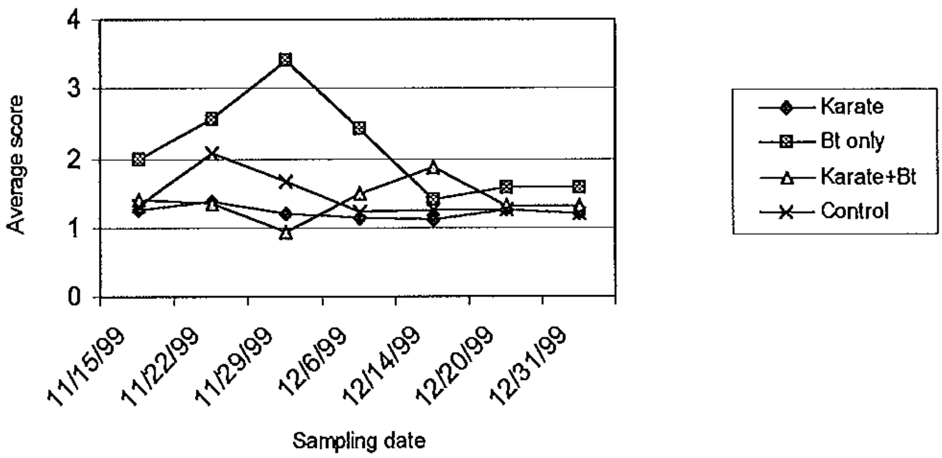


Figure 3.14:Pattern of damage in different treatments at JKUAT

The Spearman's Rank order correlation analysis outputs for each treatment are shown in the next tables (3.3 to 3.10). In all Karate and the Karate + Bt plots at JKUAT there was no aphid species that showed a significant correlation with damage. This is because the aphids' populations had been reduced by the done twice, this is, 2 weeks after transplanting and 21 days to maturity at an average rate equivalent of 180 kg/ha (Ngugi *et al*, 1979; Watts & Watts 1940)

Watering started immediately after transplanting and was done three times a week at each site until the rains started. At Limuru site a watering can was used while overhead sprinklers were used at JKUAT. Overhead sprinkling was reduced at JKUAT when sampling of aphids started, in order to avoid bias in the counts that might be caused by aphid knock-off by overhead sprinkling. It also coincided with the beginning of reliable rainfall.

Hand weeding and hoeing was done as the need arose at each site. The weed problem was more severe at JKUAT than at Limuru.

2.3 Treatments

Four sets of treatments were applied (i.e. three treatments with insecticides and one without). The treatments, each with three replicates, were as follows: -

1. Standard treatment with a pyrethroid insecticide – Lambda-Cyhalothrin (Brand name; 'Karate') which kills aphids.
2. Treatment with *Bacillus thuringiensis* (*Bt*) toxin (Brand name – 'Dipel 2X') which selectively kills DBM, leaving the aphids alive (Loehr, 1999 personal communication).
3. Treatment with both Bt and the pyrethroid – Lambda-Cyhalothrin (Karate) for killing both DBM and aphids.
4. No treatment at all (Control)

The treated replicates comprised the experiment set whereas the untreated replicates comprised the control. There was random allocation of treatment and no treatment (Murdie, 1972) giving a completely randomized block design - CRBD (Krebs, 1989).

Bt is highly effective against DBM that are resistant to conventional insecticides (Sun *et al*, 1986) but does not harm the hymenopterous parasitoids of DBM (Bruner and Stevens, 1986). Bt is also known to be ineffective against aphids. Therefore Dipel 2x was used in this project as a selective pesticide against DBM.

2.3.1 Spraying regime and technique

Before treatments started, sampling was done to check whether the pests had attained the necessary economic threshold levels to warrant treatments. The following economic threshold level was used for DBM: - More than 2 (3^{rd} or 4^{th} instar) larvae per plant at early stage and more than 5 (3^{rd} or 4^{th} instar) larvae per plant before heading (Suey-Sheng Kao and Ching-Chou Tzeng, 1995)

A standard 15 liters knapsack sprayer was used for the application of the pesticides. The volume and frequency of application varied with the changes in the pests' infestation levels and the stage of growth of the cabbage plants. Weekly sampling was done to assess pest infestation levels and also to determine spraying needs.

NB: On each treatment date, treatment was done after sampling on that day. Therefore a treatment had no effect on the sampling outcome for the day on which the treatment was done. Effect of treatment on day 1 of sampling could only be seen on day 2 of sampling.

The following tables show the treatments and their application rates and intervals. Treatments were administered once the pest infestation levels reached the economic threshold levels mentioned above.

Table 2.1:Bt applications

(Standard rate = 5 g a.i. per 10 liters of H2 o)

Site	Occasion	Date	Total a.i Used (g)	Treated plots	Plot code
JKUAT	1	8/11/99	10 g	T_2&T_3	A, E, J:C,D,I
"	2	15/11/99	12.5 g	"	"
"	3	6/12/99	15 g	"	"
"	Last	14/12/99	15	"	"
LIMURU	1	11/11/99	10 g	T_2&T_3	C,F,G:B,D,K
"	Last	18/11/99	12.5	"	"

Table 2.2: Karate application

Standard rate = 2.5 ml a.i. per 10 l of H_2o

Site	Occasion	Date	Total a.i Used	Plots treated	Plots code
JKUAT	1	8/11/99	6.25 ml.	T_1 & T_3	F,G,K:C,D,I
	Last	22/11/99	8.75 ml.	"	"
LIMURU	1	11/11/99	3.75 ml	"	A,H,L:B,D,K
	Last	18/11/99	7.5 ml	"	"

NB: a.i. = active ingredient

2.4 Sampling

Sampling was done in 20 randomly selected farmers' fields adjacent to the Limuru field experiment site. This was done with a view of assessing the magnitude of the aphid problem (i.e. distribution of aphids' relative abundance of each species & their relation to crop damage (Kaelin & Aver, 1954; Strickland, 1961; Chiang *et al,* 1961; Natural academy of sciences, 1969 – in Southwood (1994)) in the study area. This was supplemented by questionnaires filled out by the researcher during interview with farmers. The questionnaires were used to gather information on farmers' knowledge, attitude and practice (KAP) in regard to cabbage aphids and their control (Appendix 1).

Sampling was also carried out in the field experiment sites at JKUAT and Limuru. This was to assess fluctuations in DBM (for the purpose of treatments) and determine the relative abundance of the three aphid species and relate their populations to crop damage (Kaelin & Aver, 1954; Chiang *et al*, 1961 – in Southwood (1994)). Percentage parasitism was estimated and aphid parasitoids and hyperparasites hatching out from the reared samples were identified (Stary, 1970) and the parasitoid complex identified.

2.4.1 Sampling technique

Stratified random sampling was done by taking aphid counts on three leaves: outer crown, middle of the plant, and near the base of a randomly selected plant. Prior to each sampling visit to the field site two sets of ten plants each were randomly selected for sampling using random numbers generated from a scientific calculator. Such ten randomly selected plants were sampled in each plot at weekly intervals on each site.

This method was a slight modification to the 'three-leaf' method of Church and Strickland (1957). *In situ* counts were done by grasping the leaf petiole by the

Karate and the remaining few did not cause any significant damage in these plots. In non Karate-treated plots *Brevicoryne brassicae* showed higher correlation (at 5% significance level) with damage.

In Limuru *B.brassicae* showed significant correlation (at 5% level of significance) with crop damage higher than other aphid species in Karate + Bt, and Bt-only plots. *B.brassicae* also showed higher correlation to crop damage than the other species in Karate-only plots – but the correlation was insignificant at 5% significance level. In the Controls *Myzus persicae* and *L. erysimi* showed a statistically higher correlation to crop damage than *B brassicae*.

The R and p-levels shown in bold in the following tables are those that show significant correlation at 95 % confidence limit **($p < 0.05$)**

Table 3.3: Spearman Rank Order Correlations JKUAT-Karate only

	N	R	t(N-2)	p-level
B.brassicae & Damage	7	.127294	.286972	.785646
M.persicae & Damage	7	.204124	.466252	.660642
L.erysimi & Damage	7	-.103935	-.233671	.824506

Table 3.4: Spearman Rank Order Correlations JKUAT-Bt only

	N	R	t(N-2)	p-level
***B.brassicae* & Damage**	7	**.881818**	4.181190	**.008645**
***M.persicae* & Damage**	7	**.900000**	4.616902	**.005752**
L.erysimi & Damage	7	.576551	1.577859	.175427

Table 3.5: Spearman Rank Order Correlations JKUAT- Karate + Bt

	N	R	t(N-2)	p-level
B. brassicae & Damage	7	-.165145	-.374415	.723449
M. persicae & Damage	7	0.000000	0.000000	1.000000
L. erysimi & Damage	7	.000000	.000000	1.000000

Table 3.6: Spearman Rank Order Correlations JKUAT- Controls

	N	R	t(N-2)	p-level
***B. brassicae* & Damage**	7	**.792825**	2.908873	**.033444**
M. persicae & Damage	7	.718182	2.307811	.069096
L. erysimi & Damage	7	.623085	1.781313	.134966

Table 3.7: Spearman Rank Order Correlations Limuru- Karate Only

	N	R	t(N-2)	p-level
B. brassicae & Damage	7	.676467	2.053877	.095172
M. persicae & Damage	7	-.103935	-.233671	.824506
L. erysimi & Damage	7	.311805	.733799	.496016

Table 3.8: Spearman Rank Order Correlations Limuru- Bt only

	N	R	t(N-2)	p-level
B. brassicae & Damage	7	.954994	7.199069	.000806
M. persicae & Damage	7	.836364	3.411622	.019010
L. erysimi & Damage	7	.798199	2.962888	.031414

Table 3.9: Spearman Rank Order Correlations Limuru- Karate + Bt

	N	R	t(N-2)	p-level
B. brassicae & Damage	7	.857143	3.721042	.013697
M. persicae & Damage	7	.018712	.041849	.968239
L. erysimi & Damage	7	.000000	.000000	1.000000

Table 3.10: Spearman Rank Order Correlations Limuru- Controls

	N	R	t(N-2)	p-level
B. brassicae & Damage	7	.774806	2.740466	.040769
M. persicae & Damage	7	.857143	3.721042	.013697
L. erysimi & Damage	7	.857143	3.721042	.013697

3.4 Percent parasitism on cabbage aphids

3.4.1 Patterns of parasitism

The patterns of parasitism of the aphid populations by *D.rapae* (the only primary parasitoid recorded) at both sites (JKUAT and Limuru) are shown in Figures 3.15 and 3.16.

The patterns of parasitism were similar in Karate-treated plots and also in non karate-treated plots. In the Control plots parasitism seemed to increase gradually through the season. A similar trend seemed to apply for the *Bt* only-treated plots.

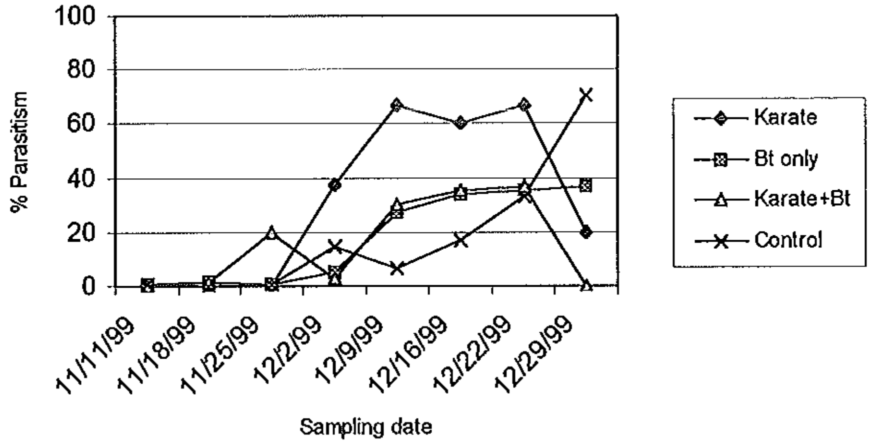


Figure 3.15: Mean percent parasitism/10 plants against time -Limuru

Data used are shown in appendix 5

Percent parasitism at Limuru was low at the beginning. It then rose sharply in Karate-only and Karate + Bt plots from the 25th of November and gradually in the Control. In Karate only and Karate + Bt plots parasitism sharply dropped again from the 22nd of December (2-3 weeks to harvest) while it continued to rise gradually in Bt-only and Control plots.

Percentage values and the graph indicate that parasitism was higher in Karate-treated plots than in non karate-treated plots. But it should be noted that the Karate pesticide leaving, a few most of which would then be parasitised had killed most of the aphids in the Karate-treated plots. A case in point is where on the 5th sampling occasion (9th December) the three karate-only plots had 1, 1 and 0 aphids, giving a total of 2 aphids in a sample of 30 plants (10/plot) and all the aphids were already parasitised (mummified). This gave a corresponding mean percent parasitism of 66.70 –see appendix 6.

On the same sampling occasion the three Bt-only plots had 24,102 and 88 aphids respectively (Total 214 aphids) and 15, 13 and 5 parasitised (mummies) – total 33 parasitised. This gave an average percent parasitism of 26.98%. The Karate + Bt plots had 24, 50 and 23 aphids (Total 97) and 3, 28 and 5 parasitised, giving a mean percent parasitism of 30.08%. The controls had 125, 70 and 72 aphids (267 in all) and 12, 5 and 2 parasitised: – mean parasitism 6.51%.

From the above illustration it could be safely stated that there was a relatively high number of parasitoids at work in non karate-treated plots. But due to the correspondingly higher number of aphids present the percentages are quite low.

At JKUAT also the patterns of parasitism in Karate-treated plots were similar and those in non-karate treated plots were also similar. In the Control and Bt only plots parasitism rose gradually through the season. Percent parasitism in Karate and Karate + Bt plots seem much higher than in Bt only and control from sampling occasion 1 to 5 (8th November to 14th December). However, it is also due to the fact that most aphids in Karate-treated plots were killed by karate and the few remaining were highly or fully parasitised.

At JKUAT also, higher counts of mummies were recorded in non-karate plots than in karate plots but aphid counts were overwhelmingly higher leading to correspondingly low percent parasitism in non-karate plots

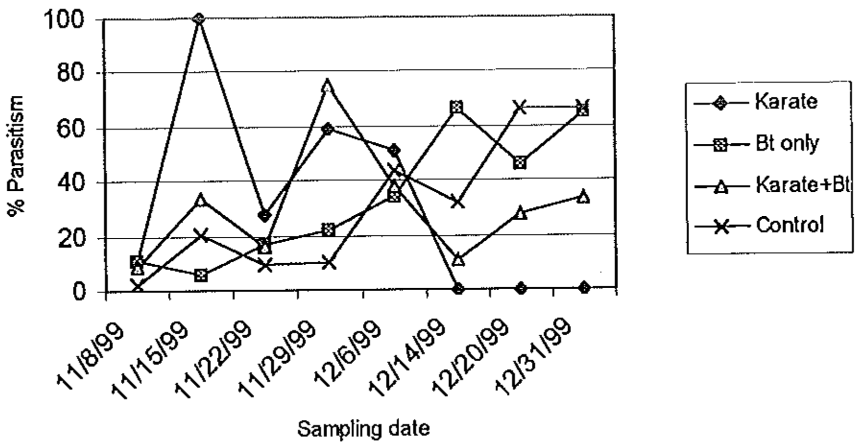


Figure 3.16. Mean percent parasitism/10 plants against time – JKUAT

Data used are shown in appendix 6

Percent parasitism not withstanding one can conclude that high aphid numbers (especially in non karate-treated plots) attracted high numbers of primary parasitoids (see also 3.5.2 for number of mummies recorded in each treatment).

Average % parasitism/10 plants for each of the treatments throughout the season were 31.36% (Karate-only), 17.6% (Bt-only), 15.77% (Karate + Bt), 17.88% (Controls) at Limuru and 31.11% (Karate-only), 33.38% (Bt-only), 30.48% (Karate + Bt) and 31.28% (Controls) at JKUAT.

3.4.2 ANOVA for percent parasitism

Percent parasitization of cabbage aphids by *D.rapae* for each treatment was subjected to a date-to-date one-way ANOVA between treatments. The output of the comparisons is summarized in tables 3.11 and 3.12.

Table 3.11. ANOVA results for percent parasitism - JKUAT

		Sum of Squares	df	Mean Square	F	P-level
8th November	Between Groups	156.970	3	52.323	.836	.511
	Within Groups	500.709	8	62.589		
	Total	657.679	11			
16th November	**Between Groups**	**15505.781**	**3**	**5168.594**	**5.473**	**.024**
	Within Groups	**7555.404**	**8**	**944.425**		
	Total	**23061.184**	**11**			
22nd November	Between Groups	538.532	3	179.511	1.376	.318
	Within Groups	1043.788	8	130.473		
	Total	1582.320	11			
29th November	**Between Groups**	**8528.669**	**3**	**2842.890**	**4.979**	**.031**
	Within Groups	**4567.836**	**8**	**570.979**		
	Total	**13096.505**	**11**			
6th December	Between Groups	496.195	3	165.398	.131	.939
	Within Groups	10106.971	8	1263.371		
	Total	10603.166	11			
14th December	Between Groups	1297.297	2	648.648	.338	.726
	Within Groups	11500.071	6	1916.678		
	Total	12797.368	8			
20th December	Between Groups	3557.211	3	1185.737	.439	.734
	Within Groups	16210.215	6	2701.703		
	Total	19767.426	9			
31st December	Between Groups	384.410	2	192.205	.066	.937
	Within Groups	14464.324	5	2892.865		
	Total	14848.734	7			□

There were no significant differences in parasitism between all treatments from 6th December to 31st December (i.e. 6th week after transplanting to harvest time). This might probably have been due to the fact that from the 6th week cabbage heads started forming and aphid infestations generally fell. By this time also (6th week) Karate treatments had been stopped due to lack of proper thresholds. Hence all the plots were in similar conditions in that none was receiving Karate.

Table 3.12. ANOVA results for percent parasitism – Limuru

		Sum of Squares	df	Mean Square	F	p-level
11th November	Between Groups	2.279	3	.760	1.173	.379
	Within Groups	5.178	8	.647		
	Total	7.457	11			
18th November	Between Groups	4.197	3	1.399	.754	.550
	Within Groups	14.838	8	1.855		
	Total	19.035	11			
25th November	Between Groups	774.058	3	258.019	.823	.517
	Within Groups	2507.998	8	313.500		
	Total	3282.056	11			
2nd December	Between Groups	2282.063	3	760.688	.831	.513
	Within Groups	7319.841	8	914.980		
	Total	9601.904	11			
9th December	Between Groups	5638.095	3	1879.365	1.557	.274
	Within Groups	9658.836	8	1207.355		
	Total	15296.931	11			
16th December	Between Groups	2833.599	3	944.533	.668	.595
	Within Groups	11319.634	8	1414.954		
	Total	14153.233	11			
22nd December	Between Groups	2263.004	3	754.335	.656	.602
	Within Groups	9203.583	8	1150.448		
	Total	11466.588	11			
29th December	**Between Groups**	**8022.329**	**3**	**2674.110**	**4.345**	**.043**
	Within Groups	**4923.345**	**8**	**615.418**		
	Total	**12945.675**	**11**			□□

3.5 Parasitoid complex

3.5.1 Parasitoid complex of cabbage aphids

In the analysis of the reared material three different species of parasitoids were identified. Out of these *Diaeratiella rapae* (McIntosh) was the only primary parasitoid recorded.

Although whitish mummies (characteristic of *Proan volucre* parasitization) were occasionally collected in the field no *Proan volucre* were recovered from the reared material.

The other two parasitoid species identified were *Alloxysta sp* (an endoparasitic hyperparasitoid) and *Pachyneuron sp.* (an ectoparasitic hyperparasitoid). These were the only hyperparasitoids (secondary parasites) recovered from the reared material. Detailed classification is given below.

Table 3.13: Classification of the collected parasitoids

ORDER	**FAMILY**	**GENUS**	**Species**	**TYPE OF PARASITOID**
HYMENOPTERA	APHIDIIDAE	*Diaeratiella*	*rapae*	Primary aphid parasitoid
HYMENOPTERA	CYNIPIDAE	*Alloxysta*	*Alloxysta Sp.*	Endoparasitic Hyperparasitoid
HYMENOPTERA	PTEROMALIDAE	*Pachyneuron*	*Pachyneuron Sp.*	Ectoparasitic Hyperparasitoid

The parasitoid complex of cabbage aphids was elucidated and is summarized in figure 3.17.

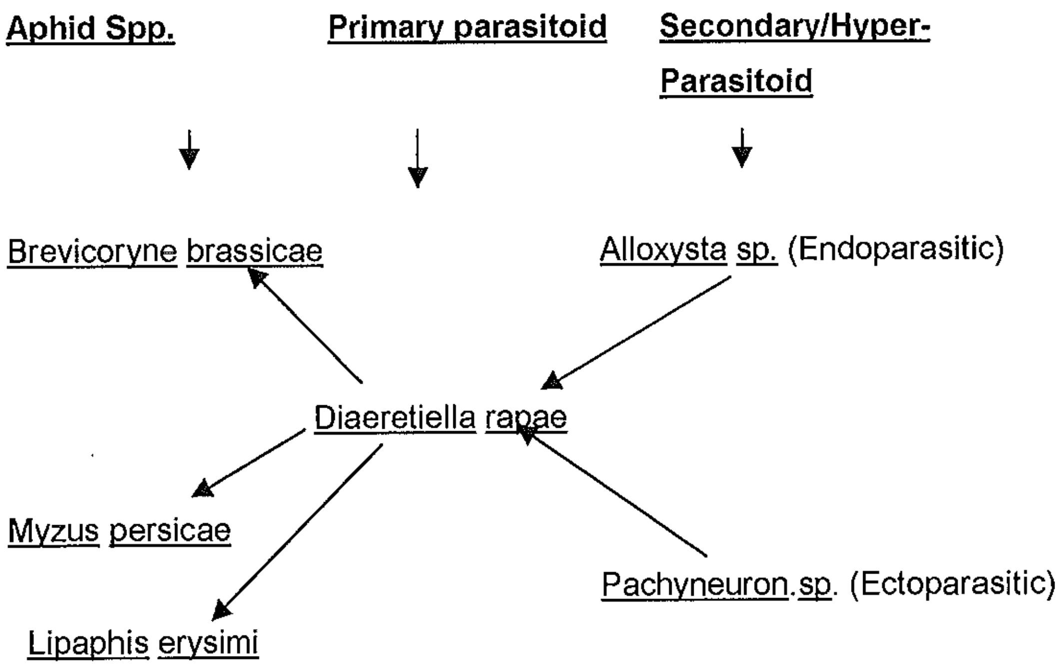


Fig 3.17 Parasitoid complex of cabbage aphids in Limuru and Thika (Kenya) – in November 1999 – January 2000

3.5.2 Relative proportions of primary and secondary parasitoids

The relative proportions of the emerged primary and secondary parasitoids for JKUAT are shown in Figures 3.18-3.21.

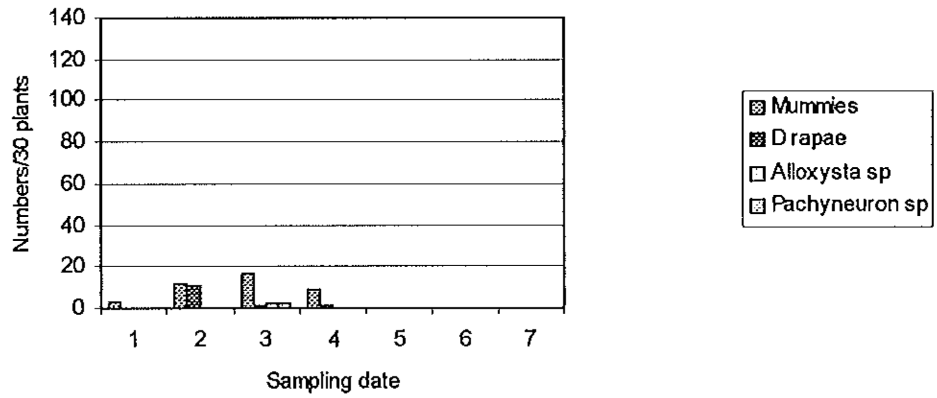


Figure 3.18:Relative proportions of primary- and hyper-parasitoids; Karate-JKUAT

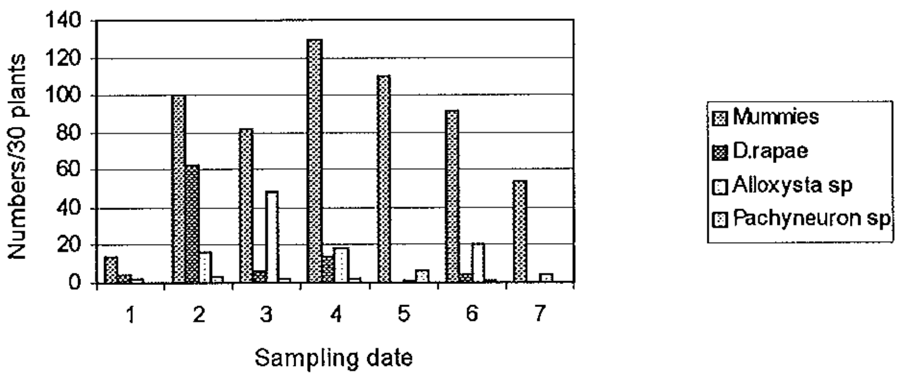


Figure 3.19:Relative proportions of primary- and hyper- parasitoids Bt only –JKUAT

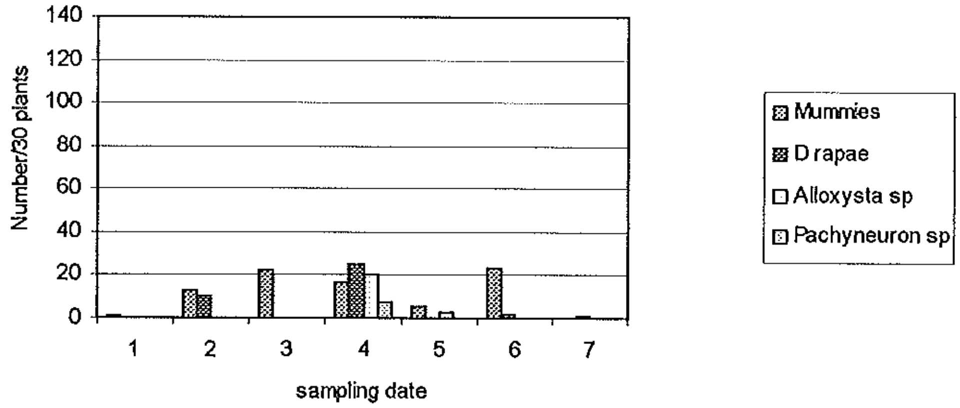


Figure 3.20:Relative proportions of primary- and hyper- parasitoids Karate + Bt – JKUAT

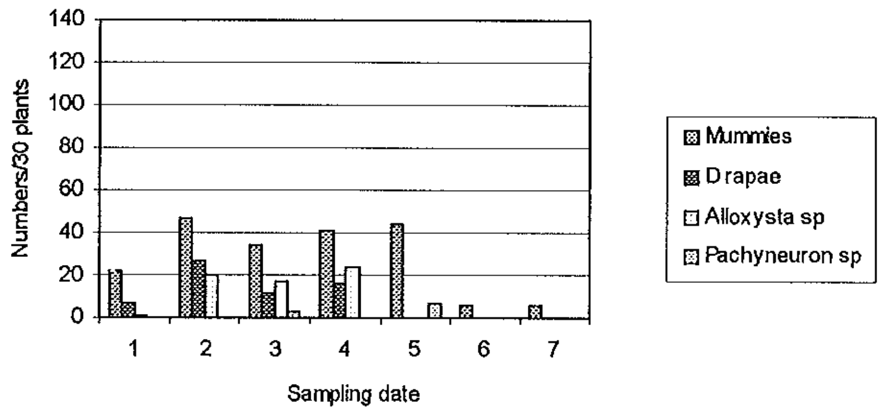


Figure 3.21:Relative proportions of primary- and hyper- parasitoids Control – JKUAT

Comparatively fewer mummies were recorded from Karate-only (highest count = 16) and Karate + Bt-plots (highest count = 23 mummies) than from Bt-only –

(highest count = 130 mummies) and controls – (highest count = 47 mummies). More *D.rapae* emerged from Bt-only and Control samples than from Karate + Bt-plots respectively. *Alloxysta sp* was the most abundant of the two hyperparasitoids and hence it is more destructive to primary parasitoid.

In Karate-only plots hyperparasitoids were recorded only once on the 3rd sampling occasion whereas in Karate + Bt-plots the hyperparasitoids were recorded on occasion 4 and 5 only. Karate-treated plots the proportion of *D.rapae* was evidently higher than that of the hyperparasitoids. The reverse was true for non karate-treated plots where the hyperparasitoids were proportionately higher than *D.rapae* (the primary parasitoid).

Figures 3.22-3.25 summarize the proportions of emerged primary and secondary parasitoids at Limuru

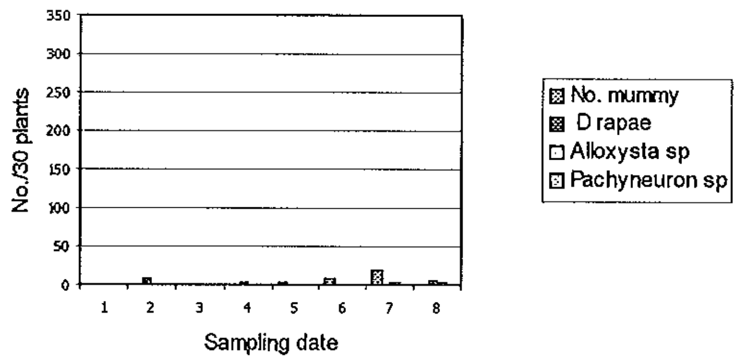


Figure 3.22:Relative proportions of primary- and hyper- parasitoids Karate-Limuru

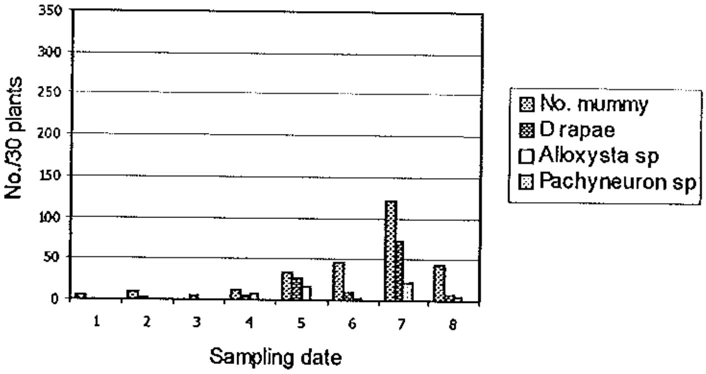


Figure 3.23:Relative proportions of primary- and hyper-parasitoids Bt only –Limuru

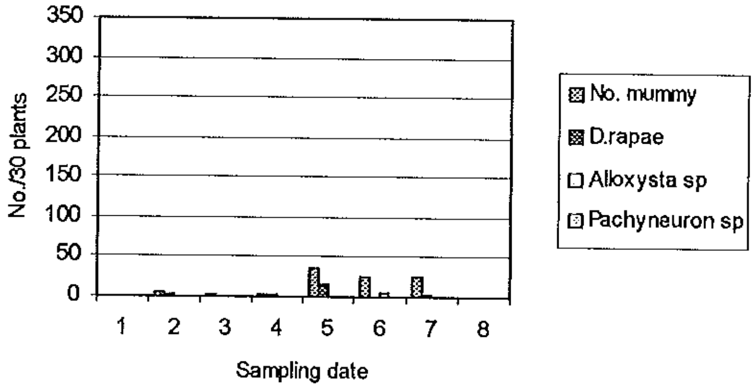


Figure 3.24:Relative proportions of primary- and hyper-parasitoids Karate + Bt – Limuru

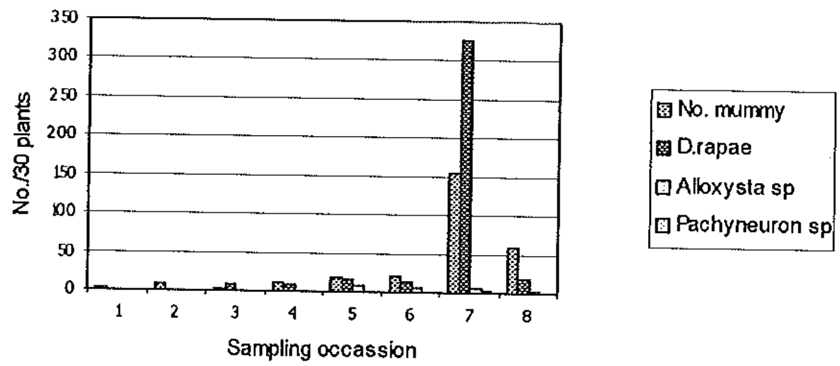


Figure 3.25:Relative proportions of primary- and hyper-parasitoids Controls –Limuru

The pattern of emergence resembles that for JKUAT samples in that few hyperparasites emerged from Karate-treated plots as compared to non karate-treated plots. Unlike at JKUAT, however, the proportion of the primary parasitoid (*D. rapae*) seems to have been higher than that of the hyperparasitoids in all the treatments.

3.6 Other recorded natural enemies of cabbage aphids

In this study the recorded natural enemies of aphids were mainly ladybird beetles (Coleoptera) and their larvae. Other insects collected included *Charops sp* (Ichneumonidae), another Ichneumonidae (wasp-like) and a Dipteran both of which are yet to be fully identified.

The role of these insects is uncertain but it is highly suspected that they are ectoparasitic to aphids; and not parasitoids since they are a little bigger than common aphid parasitoids. The wasp-like Ichneumonidae, which had characteristic yellow and black coloration, was observed on several occasions hovering closely over aphid colonies and eventually landing and apparently inserting its ovipositor into the colony of aphids. The classification of these insects is summarized in Table 3.14 below.

Table 3.14: Classification of collected aphid natural enemies

ORDER	FAMILY	GENUS	SPECIES	ROLE IN APHID CONTROL
Coleoptera	Coccinellidae	*Cheilomenes*	*Cheilomenes_lunata*	Aphid predator (ladybird beetle)
Coleoptera	Coccinellidae	*Hippodamia*	*Hippodamia variegata* (Goeze)	Aphid predator (ladybird beetle)
Hymenoptera	Ichneumonidae	*Charops*	Charops Sp.	To be confirmed
Hymenoptera	Ichneumonidae	To be confirmed	To be confirmed	To be confirmed
Diptera	to be confirmed	To be confirmed	To be confirmed	To be confirmed

3.7 Crop damage and yield results

3.7.1 Crop damage

Damage by cabbage aphids as well as diamondback moth and other pests and diseases were observed throughout the crop cycle. In the early days after transplanting gapping was done especially due to cutworm (*Spodoptera sp.)* attacks and failed seedling establishment in the field.

Aphids caused more damage in Bt only and Control plots where no Karate had been applied for aphid control. Damage by aphids was low in Karate treated plots. In some instances where aphid infestations were too high the entire plant was destroyed especially where attacks occurred during the early stages of growth. Symptoms of aphid damage included stunted growth and distortion of leaves, with distortion of leaves becoming more severe in cases of viral infections.

Less aphid attacks were observed in Karate + Bt plots. A combination of these pesticides offered better protection against) than did any one single pesticide.

3.7.2 Crop yield analysis

Introductory trials of different cabbage varieties in a previous study by KARI (1996) had shown Gloria F1 Hybrid to have an average yield of 56.1 t ha^{-1} and Copenhagen Market 43.6 t ha^{-1} (KARI, 1996). At JKUAT the greatest yield reduction was seen in karate only plots whereas at Limuru it was seen in the control plots.

Table 3.15: Harvest data: mean head-weight and mean yield-per treatment

Yield per treatment in the last column indicates marketable yield.

SITE	TREATMENT	Weight per head (grams)	Weight per plot (Kilograms)	Yield/treatment (tons ha^{-1})
JKUAT	Karate	492.32	25.69	5.90
	Bt only	563.96	27.69	6.36
	Karate + Bt	712.31	51.02	11.69
	Controls	628.78	37.94	8.71
LIMURU	Karate	2091.02	62.17	16.10
	Bt only	1511.1	82.17	21.23
	Karate + Bt	1447.2	93.25	22.27
	Controls	1455.5	45.67	11.83

Total yields per treatment were also compared. Although there was no statistically significant difference in yield Karate + Bt plots had the highest mean yield.

The mean weight/head and also mean yield/plot were lower in JKUAT where Gloria F1 hybrid was sown than at Limuru where Copenhagen Market was sown.

This lower yield from Gloria F1 hybrid, which was expected to give a higher yield than Copenhagen Market, occurred due to a sudden occurrence of root rot and other infections encouraged by heavy rains and flooding at JKUAT when the crop was almost ready for harvest. Because of this interference by external factors it was difficult to compute a fairly accurate correlation between the aphid abundance and yield. ANOVA for mean weight per head is shown below (Table 3.16).

Table 3.16: ANOVA for mean head weight

Site		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig. level**
JKUAT	Between Groups	79001.640	3	26333.880	.534	.672
	Within Groups	394802.715	8	49350.339		
	Total	473804.355	11			
LIMURU	Between Groups	871414.265	3	290471.422	2.545	.129
	Within Groups	912955.955	8	114119.494		
	Total	1784370.219	11			

CHAPTER 4 DISCUSSION AND RECOMMENDATIONS

In this study aphids and Diamondback moth were found to be the most important pests of cabbage. The farmers relied mainly on the use of pesticides and did not distinguish the pesticide that was suitable for selectively killing aphids.

The farmers' awareness of the role of natural enemies in cabbage aphids control was dismally low and their believe in the use of chemical pesticides overwhelmingly high. Although most of the farmers correctly mixed the right amount of active ingredients with the diluents (mainly water), some others added exceptionally higher amounts of active ingredients.

The latter group added the amount indicated by shopkeepers who in some cases might be misleading or they added a high amount due to their perceived believe that the higher the amount of active ingredient used the better and more immediate the results. The risk posed to beneficial insects and other non-target organisms such as earthworms seemed certainly out of question to the farmers.

Safety precautions were not generally observed and the risk of human poisoning was extremely high. The fact that pesticides were in some cases applied as late as three days to harvesting indicates the seriousness of the risk of poisoning through pesticide residues in the crop. Therefore, there is a dire need to raise farmers' awareness of the dangers of injudicious use of pesticides and the importance of natural enemies in their fields

Heong (1984) pointed out that farmers spontaneously use thresholds on their own initiative, based on the personal, subjective knowledge of the threshold, which they have acquired through years of experience (Stonehouse, 1997). The surverys showed this to be the case in the study area.

Stonehouse (1997) states that the fear of risk is best removed by an understanding of the situation, which is in turn dependent on the quality of information. He further states that the ideal way forward is the integration of 'experience' with 'learning' whereby modern and traditional agriculture learn from each other – with information moving in both directions.

In Karate-treated plots aphid counts declined after the initial pesticide applications and remained low till the crop was harvested. On the other hand in non Karate-treated plots aphid counts were high at the beginning and remained relatively so throughout the season. This would seem to imply that if pesticide treatment were applied in the early stage of cabbage growth, when aphid-infestations start to build up, effective control would be achieved.

The average score patterns for the various aphid species and damage indicated a closer correlation between the abundance of *Brevicoryne brassicae* (L) and damage. The Spearman's Rank order correlation analysis largely confirmed this finding. This might be tied to the fact that *B. brassicae* was also the most abundant of the three aphid species in almost all the cases. *B.brassicae* produces distortions of the plants unlike the other two species. Exceedingly high *B.brassicae* also lead to rotting of cabbage.

In this study, aphid abundance scores and the corresponding damage scores were higher in non-karate treated plots, that is in Bt only and the control plots. At JKUAT the scores were higher for each treatment indicating a higher infestation and a correspondingly higher damage by aphids than at Limuru. The difference in scores between Karate-treated and non Karate-treated plots strongly indicates that Karate offered a definite protection from aphid damage by reducing their numbers.

Karate was applied only twice at both Limuru and JKUAT in the whole season. This indicates that applying the pesticide in the early stages when the infestations are high and leaving the natural enemies to suppress the pest population during the rest of the season can economically protect the crop. The ANOVA shows that from the 7th week after transplanting (and after treatments for aphids have ceased) there is no significant difference in aphid counts in all the treatments. Control measures should therefore be applied earlier to minimize damage.

Percent parasitism appears higher in Karate-treated plots especially in the first five sampling weeks (3rd – 7th week after transplanting). It should however be noted that actually what was happening is that the pesticide (Karate) was killing most of the aphids leaving a few -most or all of which would then be parasitized. At JKUAT on sampling occasion 2, for instance, only 1 aphid (each already mummified) was collected out of ten plants sampled in each plot.

This gave corresponding 100% parasitism/10 plants for Karate-only plots, a figure that would be quite misleading at face value. These percentages would however seem to complement the findings of Bahana and Karuhize in 1986 in their study on the role of *D.rapae* in the population of the cabbage aphid (*B. brassicae*) in Kenya – that high parasitism coincided with a decline in aphid population.

In the non Karate-treated plots, on the other hand, higher numbers of mummies were recorded, but the total aphid counts were even higher. This agrees with Hughes (1963) findings that dense colonies of aphids are attractive and favorable to natural enemies.

Higher counts of aphids than mummies in non Karate-treated plots could be due to the fact that there was a sufficient food supply for the aphids (afforded by the rapid growth of the crop). This gave them the potential to increase in numbers at a rate much faster than the parasitoids could significantly reduce.

Gamal *et al* (1992) studied the long-term effects of various insecticides on *Diaeratiella rapae* (Macintosh), a parasite of the cabbage aphid. They observed that all the insecticides used at the recommended field rates of application reduced the emergence of adult parasitoids from mummified hosts by 55-97% compared with the untreated control. They also observed that the survival and longevity of emerged parasitoids were significantly reduced by all insecticides and rates used in the study.

Percent parasitism, on mummies and total aphid counts, in the control plots strongly confirms the above suggestion. This is because in the control plots where no Bt or Karate was applied aphids' counts declined from the 7th week to harvest while parasitism gradually rose within the same period.

The pattern of parasitism in the control plots at both sites, whereby it gradually rose from 0.64 to 70.56% at Limuru and from 1.91 to 66.67% at JKUAT indicates that the parasitoid (*D.rapae*) played a key role in suppressing aphid populations. Parasitism also increased gradually in Bt-only plots from 1.02 to 36.45% at Limuru and 10.7 to 65.2% at JKUAT – further confirming that parasitism was an important factor in aphid control. ANOVA (Table 7) showed no significant difference in parasitism between Bt-only- and control- plots further confirming the foregoing statements.

D.rapae was the only primary parasitoid recorded from the reared material. However observation of whitish mummies characteristic of *Proan volucre* Parasitization might mean that few *P.volucre* might also have been attacking the aphids but hatched out in the field before mummies were collected. The whitish mummies might also have been due to *D.rapae* Parasitization on *B brassicae*, which at times give whitish-yellow mummies.

Charops sp. was observed hovering among aphid colonies in the field, although none was recovered from the material reared in the laboratory. This parasitoid has been reared in the past from bollworm (*Helicoverpa armigera*) collected from tomato in Kiambu in Kenya by Oduor *et al* (1998).

Despite the large numbers of mummies collected at JKUAT from non Karate-treated plots a very small number of the primary *parasitoid (D.rapae)* emerged from them.

It was also observed that more secondary parasitoids (i.e. *Alloxysta Sp.* and *Pachyneuron sp.*) emerged in comparison to the primary parasitoids especially from the 4th week after transplanting to harvest time. On the other hand, more primary parasitoids (*D.rapae*) than secondary parasitoids emerged from the few mummies collected in the Karate-treated plots.

This might imply that Karate had a repellant effect to the secondary parasites and therefore they migrated and could not parasitize the primary parasites.. Since the observed emergence of the primary parasitoids was also low in the controls where no *Bt* was applied one might safely conclude in the favor of the former argument that Karate repelled the hyperparasites. Although it is also likely that Karate repelled *D.rapae* also it could have been more repulsing to the hyperparasites than *D.rapae.*

Various authors have already reported the effect of pesticides interrupting or fully inhibiting the oviposition endeavors of parasitoids.In a study to determine the effect of Pirimicarb on foraging behavior of *Diaeratiella rapae* (Hymenoptera: Braconidae) on host-free and infested oilseed rape plants

Umoru *et al* (1996) established that pirimicarb affects the activity of *D.rapae,* causing them to spend proportionately more time walking and much less time resting whilst on contaminated plants. The pesticide appeared to act as an irritant, deterring the parasitoid from resting on contaminated surfaces and thereby stimulating them to carry on walking in search of uncontaminated areas. This reduces their chances of encountering and hence of ovipositing in aphid hosts whilst on the plant. In addition it increases the exposure of the parasitoids to insecticide by increasing their movement through contaminated surface areas.

The results also showed that more *Alloxysta sp.* (which is an endoparasite hyperparasite) than *Pachyneuron sp.* (an ectoparasitic hyperparasite) emerged. The endoparasitic hyperparasite (*Alloxysta sp.*) deposits its egg inside the primary parasitoid larvae (*D.rapae*) which itself is already inside the host aphid. The ectoparasitic female hyperparasite on the other hand, deposits her egg on the surface of the primary parasite larva (already inside a mummified aphid). There is more synchronization between the endoparasitic hyperparasite and the primary parasitoid than between the ectoparasitic hyperparasite and the primary parasite (Daniel and Sullivan, 1988). This makes *Alloxysta sp.* a more effective hyperparasite than *Pachuneuron sp.* and probably explains why the counts of Alloxysta are higher.

The fact that more hyperparasitoids than primary parasitoids emerged from materials collected from non Karate-treated plots than from Karate-treated plots might also explain why percent parasitism (which is basically a measure of primary parasitism) appeared to be higher in Karate-treated plots than non Karate-treated plots

Emergence patterns for the materials collected at Limuru largely resembled that of JKUAT except for the control plots. The samples from the control plots in Limuru had increasing numbers of the primary parasitoid emerging through the season. This explains why the percent parasitism, for the control plots, rose gradually through the season.

The percent parasitism in this study was calculated on the basis of the numbers of collected mummies. The number of emerged primary parasitoids was used only where some primary parasitoids emerged after incubation whereas no mummies had been formed at the time of sample collection

This calculation approach was based on the fact that *Diaeratiella rapae,* the primary parasitoid of interest in this study, has been reported by Broussal (1969) to be at times unable to recognize already parasitized aphids in the case that they contained only parasite embryos (Stary, 1970). In such a case if a *D.rapae* happened to oviposit in an already parasitized aphid two parasitoids might emerge from one mummy giving a misleading higher count.

On the other hand, Bueno *et al* (1992) studying the ethology and lifespan of *Diaeratiella rapae* found the development from egg to adult ranging from 8 to 15 days. The life cycle was 8 to 18 days for the female and an average of 10 days for the males. The lifespan for virgin adults, which were fed, averaged to 4.1 for females and 2.5 for males whereas for starved females it was 1.28 and 1.43 for starved males. This study was also conducted in the open field and hence an open population where a parasitoid could emerge and leave the mummy behind. The parasitism levels would therefore be underestimated if one relied on the counts of emerging primary parasitoids.

Although other natural enemies especially ladybird beetles were recorded their efficiency in regulating populations of the cabbage aphids was not assessed. It would be worthwhile to study the efficiency of these natural enemies along with parasitoids in regulating aphid populations.

The observed mean weights per cabbage head and mean yields per plot at JKUAT showed that there was higher yield (in quantity and quality) from the plots where both pesticides were applied Karate + Bt plots. This might be because infestations were more severe at JKUAT than at Limuru. Gloria F1 hybrid variety might have been more attacked by aphids or the climatic factors might have been conducive to the pest.

Mean weight per head for the harvest at Limuru showed that the Karate-only plots gave better quality heads than even where both Karate and Bt were applied. No immediate explanation exists for this but the mean yields per plot show that the best total yield was from plots treated with both Karate + Bt.

In conclusion *Brevicoryne brassicae* was found to be the most important of the three aphid species with regard to damage due to direct feeding. *Brevicoryne brassicae* that was also found to be the most abundant remains the most important of the three species in terms of damage to cabbage. *Lipaphis erysimi* was seen to be the least important of the three species.
It is believed that *Myzus persicae* and *Lipaphis erysimi* are somehow beneficial because they allow for build-up of parasitism without harming the crop (Loehr personal communication.). This was largely found to be the case in this study because even when these species were more abundant than *Brevicoryne brassicae* the damage was low and parasitism high.

The parasitoid complex for cabbage aphids comprised of *Diaeratiella rapae* as the only primary parasitoid and *Alloxysta sp* (=Charips) and *Pachyneuron sp* as the secondary parasitoids hyperparasitoids).

On the basis of the findings in this study it is recommended that; although over the years farmers have gained a lot of 'experience' in pest control practices, some of the 'experience' is harmful and should be replaced with more scientific and rational ideas. Since extension service may not be able, or may not be available, to deliver the much-needed farmers' education, horticultural organizations and the relevant government arms should come to their rescue.

Farmers' Field Schools (FFS) should be established and intensively utilized, as they would also create an environment where modern and traditional agriculture learns from each other. The findings in this study should be disseminated to the farmers are the ultimate beneficiaries. Where pests are not reaching epidemic levels applying pesticides sparingly and leaving the rest to natural enemies would be good IPM recipe.; - something that farmers should be taught.

Future research thrust should focus on the impact of Karate and *Bt* on the emergence of primary and secondary parasitoids. Ways of enhancing the work of primary parasitoids while at the same time dampening that of hyperparasitoids should also be explored. The possible roles of *Charops sp* and the other Ichneumonidae and Diptera in aphid control should also be investigated further. The possible beneficial role of *Myzus persicae* and *Lipaphis erysimi* whereby they allow for build-up of parasitism without harming the crop should also be investigated further. Further studies stretching over several seasons should be done to establish whether more parasitoid species are involved in the cabbage aphids' parasitoid in Kenya.

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6. APPENDIX

Appendix 1: A sample of the questions (in the questionnaire) asked to farmers during interviews and field surveys

3.1 Your name please? ______________________

3.6 How many years have you been farming cabbage? _______

3.9 Land tenure and use: Own land _____ acres; rented ___ acres

4.1 What is the size of your cabbage field? _______ Acres

5.1 What are your most important problems in the cultivation of cabbages (**in general**)?

5.2 What are your most important **pest and disease** problems (insect fungi, weeds, etc)?

5.3 **INTERVIEWER: show the farmer a plant with aphids. If none, show him a picture.** What do you call this pest?

5.16. You have told me how much pesticide you use for one tank. Why do you use **this amount** and not more or less?

5.24 Do you know if there are other living beings (e.g. spiders, insects, and beetles) in your field that can help you to kill your aphids?

Appendix 2: - Abundance of aphids in different treatment plots at JKUAT

Date	Karate	Bt only	Karate+Bt	Control
1	31.33	58	5	62
2	1	101	0.3	76
3	27.67	232	27.6	144
4	9	251.33	1	100.33
5	5.33	176	2	231.33
6	0	202		15.67
7	1	241	8.6	2
8	0	57.67	0.6	2.33

Appendix 3: - Abundance of aphids in different treatment plots at LIMURU

Date	Karate	Bt only	Karate+Bt	Control
1	131	173	147	215
1	90	307	170	105
1	63	264	107	280
2	170	541	188	769
2	0	103	102	127
2	0	433	97	610
3	0	787	0	415
3	0	291	5	378
3	0	243	1	197
4	16	73	0	21
4	1	47	0	196
4	0	75	25	77
5	1	24	24	125
5	1	102	50	70
5	0	88	23	72
6	3	6	0	43
6	5	88	6	28
6	0	65	27	138
7	15	215	22	645
7	4	84	6	65
7	0	86	48	28
8	0	98	0	30
8	0	31	0	4
8	10	50	0	55

NB: Table shows counts per replicate eg.1, 1,1 = replicates for date 1.

Appendix 4: Average mean scores for each aphid species and for damage

Site	Treatment	Average mean score/10 plants			
		B. brassicae	***M. persicae***	***L. erysimi***	**Damage**
JKUAT	T1 (Karate)	1.33	1.12	1.12	1.22
	T2 (Bt only)	1.80	1.27	1.14	2.14
	T3 (Karate + Bt)	1.25	1.13	1.11	1.37
	T4 (Control)	1.46	1.23	1.16	1.42
Limuru	T1 (Karate)	1.18	1.12	1.12	1.19
	T2 (Bt only)	1.91	1.35	1.41	1.95
	T3 (Karate + Bt)	1.42	1.17	1.11	1.40
	T4 (Control)	1.88	1.45	1.52	2.00

ppendix 5: Mean percentage parasitism at Limuru

npling date	Mean percent parasitism			
	Karate	Bt only	Karate + Bt	Control
1	0.00	1.02	0.00	0.64
2	0.00	1.36	1.31	0.35
3	0.00	0.57	20.00	0.56
4	37.50	4.89	2.67	14.63
5	66.70	26.98	30.08	6.51
6	60.00	34.18	35.19	16.87
7	66.70	35.45	36.93	32.98
8	20.00	36.45	0.00	70.56

\ppendix 6: Mean percentage parasitism at JKUAT

mpling date	Mean percent parasitism			
	Karate	Bt only	Karate + Bt	Control
1	10.59	10.70	9.09	1.91
2	100.00	6.17	33.33	20.52
3	27.97	16.67	16.17	9.29
4	59.26	21.82	75.33	9.95
5	51.11	34.09	37.71	43.46
6	0	66.63	11.11	31.78
7	0	45.77	27.78	66.67
8	0	65.22	33.33	66.67