EFFECT OF DIFFERENT PESTICIDE MANAGEMENT OPTIONS ON THE POPULATION DYNAMICS OF APHIDS AND THEIR NATURAL ENEMIES ON CABBAGE

BY

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DECLARATION

I hereby declare that this thesis is the result of the original research work I, Forchibe Ethelyn Echep personally carried out for the award of Master of Philosophy (M. PHIL) in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS) from the University of Ghana, Legon. All references to other peoples' work have been duly acknowledged and the thesis has not been submitted in part or whole for the award of a degree elsewhere.

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ABSTRACT

Cabbage is a popular vegetable grown in Ghana and serves as an important source of livelihood for small-scale farmers, especially in urban areas. However, its cultivation encounters several constraints such as attack by insect pests. A key insect pest is aphid that cause significant to the crops as they serve as vectors of plant diseases. Farmers thus resort to indiscriminate use of insecticides to reduce the damage caused by insect pests. However, insecticides are associated with adverse environmental and health implications. The current study sought to investigate the effect of commonly used management options on the population dynamics of aphids and their natural enemies. Cabbage seedlings were planted during the major and minor seasons of 2015 in 3 x 3 m plots. Treatments comprised, two (2) synthetic insecticides (chlorpyrifos and lambda-cyhalothrin) three (3) botanicals (hot pepper fruit extract, neem seed extract, solution of local soap ('alata samina') and water. Ten cabbage leaves per treated plot were randomly sampled weekly into 70% alcohol to obtain counts of aphids and their natural enemies. Weekly field observations were carried out to determine the number of other natural enemies and insect pests per treatment plot. Incidence and severity of a 'suspected' disease transmitted by aphids were monitored and scored twice for each season per sample. The least number of *Lipaphis erysimi* and *Myzus persicae* were recorded for the neem-treated plots, while lambda-cyhalothrin-treated plots recorded the highest number of aphids. The control and bio-pesticide-treated plots recorded the highest numbers of the natural enemies (hoverflies, ladybirds and spiders). Other insect pests observed in the field were *Plutella xylostella*, *Hellula undalis* and *Bemisia tabaci*. High population of *P. xylostella* was recorded in the chemical-treated plots compared to the biopesticide-treated plots, with neem-treated plot recording the least number. *Helula undalis* was highest in the control plots while *B. tabaci* was lowest in the neem-treated plot compared to the others. Disease incidence and severity

of 'suspected' viral disease was highest in the control and pepper-treated plots, followed by alata samina and lambda-cyhalothrin-treated plots. The highest marketable yield was recorded for the neem-treated plots for both seasons. The yield and marketability of cabbages obtained from plots sprayed with *alata samina* and pepper were also higher than that obtained from control, lambda-cyhalothrin and chlorpyrifos-treated plots, with the insecticide treated plots recording the least number of marketable heads. It was concluded that, neem effectively controlled the aphids, with mild effect on their natural enemies and also improved the yield and marketability of cabbage, followed by *alata samina* and pepper. The current findings suggest neem seed extract, local soap *alata samina* and pepper, as effective and safe options for managing aphids on cabbage and other insect pests. Effect of temperature, percentage relative humidity and rainfall on the population of aphids was also investigated. Results showed that, temperature and rainfall had a significant negative correlation for the major and minor seasons on the aphid populations except relative humidity that had a positive correlation on the population.

DEDICATION

This work is dedicated to God Almighty, my parents: Mr. Forchibe Stephen Njoh and Mrs. Forchibenjoh Vivian Mawom and to my lovely son; Ian-Jaiden Kojofoh Forchibe.

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LIST OF ABBREVIATIONS

FAO – Food and Agriculture Organization of the United Nations

SIREC – Soil and Irrigation Research Centre, Kpong

ARPPIS – African Regional Postgraduate Programme in Insect Science

DBM – Diamondback moth

ANOVA –Analysis of Variance

SE – Standard Error

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CHAPTER 1

1.0 INTRODUCTION

Crops belonging to the family Brassicaceae have great economic importance worldwide as vegetables and oil seed crops (Bhatia *et al*., 2011). Examples of these crops include: cabbage, rape, cauliflower, mustard, Chinese cabbage, etc. Their cultivation serves as a good source of employment for both rural and urban dwellers (Abbey and Manso, 2004; Owusu-Boateng and Amuzu, 2013). Cabbage, *Brassica oleracea* var. *capitata* L. (Brassicaceae) for example, is a useful exotic leafy vegetable known to originate from Southern Europe and the Mediterranean regions (FAO, 2000). It is a cold seasoned crop, which has been domesticated and used for human consumption since the ancient times (Henry, 1827; Smith, 1995). Cabbage was ranked as one of the top twenty vegetables and an important source of food globally by the Food and Agricultural Organisation of the United Nations (FAO, 1998). It is now one of the most popular vegetables grown globally in more than 90 countries including the tropics (FAO, 1998; Obeng-Ofori, 1998; Sawant *et al*., 2010). This cruciferous vegetable is low in saturated fat, cholesterol, high in dietary fiber, vitamin C, vitamin K, foliate, potassium, manganese, vitamin A, thiamin, vitamin B6, calcium, iron and magnesium for healthy body development (USDA, 2009). It is usually consumed raw, in salads, sandwiches and hamburgers or cooked, in sauces (Baidoo *et al*., 2012).

Despite the enormous benefits of cabbage, its production is constrained with insect pests attack, leading to a significant reduction in its yield and quality, thereby affecting its market value and farmers' interest to cultivate them (Zehnder *et al*., 1997; Sachan *et al*., 2008; Fening *et al*., 2013). A study conducted in Southwestern Ontario in Canada concluded that attack by insect pests alone contributed about 50 % yield loss of cabbage (Tolman *et al*., 2004). The key insect pests of cabbage in Ghana include diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae), cabbage webworm, *Hellula undalis* Fabricius (Lepidoptera: Crambidae), and aphids, *Brevicoryne brassicae* L., *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) (Mochiah *et al.*, 2011; Amoabeng *et al.*, 2013; Fening *et al.*, 2013, 2014a). Aphids are important pests of brassicas (Rohilla and Kumar, 1991; Bhatia and Verma, 1994; Dattu and Dattu, 1995; Munthali *et al*., 2004), and can cause total crop loss on brassica leafy vegetables (Mc Cullum et al., 1992). Their pest status is enhanced by their ability to reproduce rapidly, with one mature aphid giving birth to 2 to 5 live young per day which mature in 5 to 7 days after birth (Myburgh, 1993). *Lipaphis erysimi* Kalt. however, is an important aphid which attacks cabbage in Benin (James *et al*., 2010; Sæthre *et al*., 2011; Vidogbéna *et al*., 2015) and could possibly be present as well in Ghana, although not yet reported.

Aphids infest leafy vegetables in large numbers by attacking the leaves and other growing points (Munthali and Tshegofatso, 2014). All the nymphal and adult stages are phloem feeders (Hughes, 1963), and their feeding results in weak, wrinkled leaves that are cupped both outward and inward, resulting in a deformed plant with lower yields (Hughes, 1963; Mochiah *et al*., 2011). Indirect damage from their feeding usually results from honeydew excretion that supports the growth of sooty mould (Hughes, 1963). In addition, aphids are vectors of several viral diseases of Crucifers, which cause significant economic losses (Flint, 1991; Blackman and Eastop 2000; Schliephake *et al*., 2000; Parker *et al*., 2003). Several control methods have been put in place for the management of aphids, with the use of natural enemies as an important strategy. These natural enemies include predators, mainly spiders (Araneae), hoverflies (Diptera: Syrphidae), braconid parasitoid; *Diaeretiella rapae* Stary and ladybird beetles (Coleoptera: Coccinellidae) (Amoabeng *et al.*, 2013; Fening *et al.*, 2013, 2014).

However, in Ghana, the main option used by farmers is frequent application of pesticides (Ntow *et al*., 2006). Though this method is effective, side effects are usually associated with its use, which includes the development of insecticide resistance; destruction of non-target organisms such as beneficial insects (pollinators and natural enemies); contamination of farm produce with insecticide residues; exposure of the user to risks of chemical poisoning; and environmental contamination (Obeng-Ofori *et al*., 2002; Timbilla and Nyarko, 2004; Ntow *et al*., 2006; Fening *et al*., 2011, 2013, 2014). As such, alternative approaches to managing pests of cabbage and other vegetables must be sought (Ntow *et al*., 2006; Coulibaly *et al*., 2007). Other options include the use of botanicals which have been reported to be more sustainable than synthetic insecticides because of their low environmental impact (Devan and Rani, 2008).

1.1 Justification

Vegetable crops are important sources of nutrients, vitamins and minerals that are essential for human health and wellbeing, particularly for children, pregnant and nursing women. Cabbage is one of the most important vegetables, making up a relevant ingredient in people's diets in both the tropical and temperate climates (Warwick *et al*., 2003). The cultivation of this vegetable provides livelihood to a large proportion of the population in Ghana, due to its growing popularity for the food industry and home consumption (Abbey and Manso 2004; Mochiah *et al*., 2011b). In Accra; the capital city of Ghana for example, there were about 800-1,000 farmers engaged in commercial urban vegetable farming where the vegetable produced were eaten by more than 200,000 urban dwellers daily (Obuobie *et al.,* 2006).

Nevertheless, attack by insect pests usually affect cultivation and production of cabbage. Of these insect pests, aphids are one of the major concerns. They can reduce plant growth by 35-75%, causing devastating damages and sometimes total crop loss on brassica leafy vegetables (Mc Cullum *et al*., 1992; Alavo and Abagli, 2011). Management of this pest have included the use of synthetic insecticides as well as botanicals, but non-judicious use of synthetic insecticides often poses environmental and health implications as well as effects on the natural enemies of the pests (Obeng-Ofori *et al*., 2002; Timbilla and Nyarko, 2004). Botanicals on the other hand, have gained popularity for use in insect pest control of vegetables due to their mild effect on natural enemies. A study by Fening *et al*., (2011) demonstrated the potential of low doses of garlic and hot pepper in the management of insect pests of cabbage with minimal effect of their natural enemies, while Amoabeng *et al*., 2013 and Fening *et al*. (2013, 2014a) reported that lambda-cyhalothrin, a pyrethroid caused a great reduction in natural enemies' abundance. It is therefore, necessary to establish the effect of different pesticide management options on the populations of these aphids and their natural enemies, as this will help provide good grounds for developing sustainable pest management strategies for this important pest of brassicas.

Additionally, aphids being important vectors of several viral diseases, may be associated with a 'suspected' viral disease which now occurs on cabbage (Per. comm. K.O. Fening). Proper identification of the aphid species is vital for effective control and production of healthy cabbage.

1.2 Objective

The overall objective of this study is to determine the effect of different pesticide management options on the population dynamics of aphids on cabbage and their natural enemies, in the coastal savanna zone of Ghana.

1.2.1 Specific Objectives

1. To identify the species of aphids on cabbage on the vertisols in the coastal savanna agro-ecological zone of Ghana
2. To determine the effect of neem seed extract, pepper fruit extract, local soap ('alata samina') solution, chlorpyrifos and lambda-cyhalothrin on the population of the aphids on cabbage and their natural enemies.
3. To investigate the incidence and severity of a 'suspected viral disease' on cabbage
4. To determine the effect of pesticides on the population of other key pests found on cabbage.
5. To investigate the effect of temperature, relative humidity and rainfall on the population of aphids on cabbage

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Taxonomy, origin and distribution of cabbage

Cabbage is an edible plant belonging to Kingdom: Plantae, Division: Magnoliophyta, Class: Magnoliopsida, Order: Brassicales, Family: Brassicaceae, Genus: Brassica and Species: *oleracea* variety capitata; hence, the scientific name *Brassica oleraceae* var *capitata*. Other varieties of the same plant species include: cauliflower, brocolli, kale, brussels sprout. It is thought to have been domesticated as a crop, in the Mediterranean region of Europe (Baldwin, 1995) but now it is extensively cultivated throughout the world (FAO, 1998; Obeng-Ofori, 1998). It was originally valued by ancient Romans and Greeks for medicinal purposes in a variety of ailments (Economic Research Service (ESR), 2002). Today, it is primarily valued as a fresh market vegetable, although research still continues on its medicinal aspects (Hayley and Marcia, 2006). Cabbage is cultivated from the Arctic to the Sub-tropics and at high altitudes in the tropics (Hill, 1983). It is one of the most important crops in terms of nutrition, production and consumption in West Africa (Talekar and Shelton, 1993).

2.2 Botany and agronomic practices

Structurally, cabbage is made up of short unbranched stem with an adventitious root system. The 'head' which is the edible part of the cabbage plant, is basically a large vegetative terminal bud from series of overlapping expanded leaves which covers a small terminal bud (Sinnadurai, 1992; Rice *et al*., 1993). Like other brassica, cabbage is grown from the seed, which can be done in nurseries and later transplanted, or directly in the field. It can grow on all soil types, but thrives preferably in sandy loam soil that is highly rich in organic matter (CPC, 2001a). Cabbage is known to respond well to organic manure and mineral fertiliser, particularly nitrogen and generally, needs a temperature of 15-25^{0}C for optimal growth, and is also sensitive to soil pH of 5.5 to 6.5 (Schmuttere, 1992). Cultural practices such as weeding is necessary for optimum yield.

2.3 Economic Importance of cabbage

Cabbage is a high value crop with a great demand especially from restaurants, hotels and a large section of the population in cities and urban areas (Ghana Veg, 2014). It is used in several food preparations such as stews, soups and can sometimes be consumed raw, in salads, sandwiches and hamburgers (Asare-Bediako *et al.*, 2010; Baidoo *et al.*, 2012). This crop is also easy to cultivate, and is durable in the market place hence very important (Norman, 1992)

Cabbage has high nutritive value, supplying essential vitamins, proteins, carbohydrates and vital minerals (Table 1). It is an excellent source of vitamin C and beta-carotene (vitamin A precursor). These anti-oxidants are considered helpful to combat the effects of free radicals in the human body (Timbilla and Nyarko, 2006).

Cabbage cultivation in Ghana provides an excellent source of employment for both the rural and urban dwellers, as it is grown in many rural areas as well as in the outskirts of towns and cities to be supplied fresh to the urban markets and for exports (Ghana Veg, 2014). Cabbage production also serves as a source of foreign exchange for Ghana, through exportation to other countries (Sinnadurai, 1992; Ghana Veg, 2014).

Before being thought of as a food, cabbage was valued for medicinal purposes in treating headaches, gout, boils, warts, appendicitis, ulcers and diarrhoea (Hatfield, 2004). Studies showed that those eating more cruciferous vegetables have a much lower risk of prostate, colorectal and lung cancer when compared to those who regularly eat other vegetables (Lin, 2008).

Table 1: Nutritional value - (per 100g of edible portion) of raw cabbage.

Nutrients	Value	Percentages
Energy K cal - 27	27 Kcal	
Carbohydrate (g) - 4.6	4.6g	
Protein	1.8g	
Manganese	0.16mg	8%
Magnesium	12mg	3%
Sodium	0.18mg	2%
Carotene (mcg) - 1200	1200mcg	
Vitamin C (mg) - 12.4	36.6mg	44%
Niacin (mg) - 0.4	0.4mg	2%
Riboflavin (mcg) - 90	90mcg (0.040mg)	3%
Thiamine	60mcg	5%
Potassium	18mg	1%
Zinc	1µg	
Vitamine K	76µg	72%
Iron (mg) - 0.8	0.8mg	4%
Pantothenic acid	0.212mg	4%
Sugars	3.2g	
Dietary fibre	2.5g	
Folate (vitamine B9)	43µg	
Vitamine B6	0.124mg	10%
Fats (g) - 0.1	0.1g	
Moisture(g) - 91.9	91.9g	
Waste as purchased	15%	
Phosphorous (mg) - 44	26mg	4%
Calcium (mg) - 39	39mg	4%

Source: Food and Agriculture Organization - Annual Report, 1992; USDA Nutrient Database.

2.4 Pest complex of cabbage

A wide spectrum of pests has been found to be associated with cabbage (Table 3), like any other cruciferous crop and this may be attributed to its nutritional and succulent nature (Chalfant *et al.*, 1979; CPC, 2001b). According to CPC (2001a), cabbage has about 57 major pests and 28 minor ones including pathogens. The pest complex of cabbage in Ghana is divided into two; major (cause significant damage of economic importance) and minor pest (does not cause any significant damage) (Shelton *et al.*, 1988; Fening *et al*., 2013, 2014). (table 2).

Table 2: Major and minor insect pests of cabbage in Ghana.

Major pests	**Minor pests**
Diamondback Moth, *Plutella xylostella*	green peach aphid *Myzus persicae*
Cabbage aphid, *Brevicoryne brassicae*	Cutworm, *Agrotis ipsilon*,
Cabbage webworm, *Hellula undalis*	Flea beetles, *Phyllotreta* sp.
	Cabbage looper, *Trichoplusia ni*,
	Grasshopper, *Zonocerus variegatus*
	cabbage sawfly *Athalia sjostedti*
	cabbage head caterpillar *Crocidolomia pavonna*
	cabbage white butterfly *Pieris rapae*
	cabbage flea beetle *Phylotreta spp*
	Whitefly, *Bemisia tabaci*

Source: Chalfant *et al*., 1979; Shelton *et al.*, 1988; Obeng-Ofori *et al*., 2007; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014

Table 3: Some insect pest of cabbage, their origin, distribution, description and damage.

Insect pest	Origin and distribution	Description and biology	Damage
Aphids; *Brevicoryne brassicae*, *Lipaphis erysimi*, *Myzus persicae*	origin: Europe distribution: worldwide	The adults are soft bodied and may be yellow, green, pink or brown. Winged adults are usually black. They give birth to live nymphs and can also lay eggs.	Both nymph and adults are sap feeders. They contaminate cabbage heads with their exuviae and honeydew which when attacked by a fungus, produces sooty mould, resulting in unmarketable heads. Also known to transmit several viral diseases to cabbage.
Diamondback Moth; *Plutella xylostella*	origin: Europe distribution: worldwide	Adults are greyish-brown with light brown band wings which gives a diamond-like pattern when folded. Eggs are oval and yellowish-white. Larvae are pale yellowish green with scattered erect hairs. Pupae are found in white open silky cocoon. Egg to adult, 16-23 days at 20^0C-25^0C.	Larvae feed on the underside of the leaves resulting in a 'window effect'. They feed on the growing tip, resulting in multiple head formation. They also make irregular holes on the cabbage head.

Insect pest	Origin and distribution	Description and biology	Damage
Cabbage web worm; *Hellula undalis*	Origin: first identification in Italy Distribution: worldwide	Adults are greyish-brown with yellowish-brown forewings and pale-dusky hind wings. Eggs are flattened and creamy. The larva is yellowish-grey with pinkish-brown stripes and a black head. Pupae are pale brown with dark dorsal strip enclosed in loose cocoon. Eggs hatch between 2-3 days. About 25 days to complete life cycle.	Larvae mines and feed on the growing tip of the cabbage plant, leading to multiple head formation. They also make webs and fold the foliage. Their webs may later be covered with dirt and frass.
Cabbage looper; *Trichoplusia ni*	origin: North America distribution: worldwide	Adults are grayish-brown with mottled brown forewings marked with small silvery spots. Eggs are round and greenish-white. Larvae are light green with three pairs of slender legs at the head region and three pairs of thickened prolegs at the abdomen. Pupae are green or brown enclosed in silky cocoon. Eggs hatch 3-5days and caterpillar lasts for 14-21 days before pupating and pupa stage lasts for two weeks.	Larvae feed and make large irregular holes in leaves and cabbage heads. They also contaminate the heads with their frass making them unmarketable.

Insect pest	Origin and distribution	Description and biology	Damage
Cutworm; *Agrotis ipsilon*	origin: not reported distribution: worldwide	A generation lasts for about two months. Eggs hatch in 6-8 days and develop in 20-30 days.	They usually attack the young plant in the nursery. They feed at night by cutting the young plants.
Cabbage white butterfly; *Pieris rapae*	Origin: Europe, Asia, Africa distribution: worldwide	Adults are white with white forewings and dull-yellow dusted hind wings. Eggs are usually pale yellow. Larvae has a series of yellow spots on body, velvety green in colour with short hairs on head and body and five pair of prolegs. Pupa varies in colour as it mimics with its environment. Eggs hatch in 8-10 days and larva undergo 5 instar stages and takes 15-18 days for pupa to emerge.	Larvae chew and make holes in leaves and cabbage heads. Their feeding can contaminate plant.

2.5 Aphids on cabbage

2.5.1 General morphology of aphids

Aphids are small, pear-shaped, delicate insects with soft, fragile bodies belonging to the superfamily Aphidoidea (Blackman, 1974). Adults range from 1.5 to 2.5 mm long, depending on the species. Adult aphids may be winged or wingless. Immature aphids, called nymphs, look much like adults but are smaller and wingless. Aphids may be light green, yellow, pink, purple, black or mixed colors. There can be considerable colour variation even within a small colony of a single species (Blackman, 1974). Some aphids are covered with waxy secretions (Blackman and Eastop, 1984).

The key morphological characteristics of aphids which can be used in identifying different aphid species include the length and segmentation of the antennae, the branching of the median vein of the front wing, and the size and shape of the frontal tubercles, cornicles, and cauda (Blackman and Eastop, 1984). The frontal tubercles are small, bump-like projections at the base of the antennae. The presence or absence of the frontal tubercles, and their shape, are used in identification. In aphids, there are two small pipes called cornicles or siphunculi (tailpipe-like appendages) at the posterior end that can be seen projecting upward and backward from the upper, back surface of the aphid (Blackman and Eastop 1984; Harsimran *et al*., 2013). Their length, thickness, shape and color are key characteristics for identification of aphid species. The cauda is the structure at the rear end of the body. The shape of the cauda and the appearance of the hairs on the cauda are also used in aphid identification (Blackman and Eastop, 1984; Henry, 1997). At least three species of aphids are of economic importance to these crops, including the turnip aphid, *Lipaphis erysimi*

(Kaltenbach); green peach aphid, *Myzus persicae* (Sulzer) and cabbage aphid, *Brevicoryne brassicae* (Linnaeus). All three species have been reported in some countries in Africa.

2.5.2 *Brevicoryne brassicae* (Cabbage aphid) (Hemiptera: Aphididae)

2.5.2.1 General morphology and taxonomic identification

The cabbage aphid belongs to family: Aphididae and genus *Brevicoryne*. The genus name is derived from the Latin words "*brevi*" and "*coryne*" and which loosely translates as "small pipes". The cabbage aphids are small and pear-shaped insects of 2.0 to 2.5 mm long. They are covered with a greyish waxy covering, have thick and very short siphunculi or conicles (0.06-0.07 times the body length and 0.8-1.0 times the length of the cauda), and broad triangular cauda. The short cornicles and the greyish waxy secretion that cover the aphids, helps distinguish them from other aphids that may attack the same plant (Blackman and Eastop 1984; Carter and Sorenson, 2013; Opfer and McGrath, 2013). The adult aphids maybe winged (alate) or wingless (apterae) and unlike other aphids, they can attack the crop at any growth stage, causing significant yield losses (Elwakil and Mossler, 2013).

Plate 1: Cabbage aphid, *Brevicoryne brassicae* Linnaeus, colony (courtesy: Lyle Buss, University of Florida, Entomology and Nematology Department).

2.5.2.2 Origin and distribution

The cabbage aphid is known to have originated from Europe and now has a worldwide distribution (Kessing and Mau, 1991). It is one of the commonest species to be found throughout the temperate and subtropical regions of the world. This wide distribution has no doubt been made possible by the very extensive distribution and abundance of its cruciferous host plants (Essig, 1947). Severe damages caused by this pest have been reported in many countries including Canada, The Netherlands, South Africa, USA, India and China (Carter and Sorensen, 2013).

2.5.2.3 Host status and specificity

The cabbage aphid has a host range restricted to plants in the family Brassicaceae (Cruciferae), and this includes both cultivated and wild cruciferous crops (Gabrys *et al.*, 1997). Of all cruciferous crops, cabbage aphid is an especially big problem in broccoli and cabbage production (Opfer and McGrath, 2013).

2.5.2.4 Biology and ecology

These aphids can reproduce in two ways. In warm climates (e.g., in Florida and Hawaii), females give birth to female nymphs without mating. In this case, an aphid colony consists of females only. This occurs during warmer periods in temperate climates as well. In temperate climates, however, the mode of reproduction changes during the autumn as temperatures begin to drop. For example, in response to low temperature males are also produced (Blackman and Eastop, 1984). When mating successfully takes place, the females all lay eggs. The egg stage is the overwintering stage of aphids. Generations are overlapping, with up to 15 generations during the crop season (Hines and Hutchison, 2013). The total life cycle duration ranges between 16 to 50 days depending on temperature. The life cycle is shorter at higher temperatures (Kessing and Mau, 1991).

2.5.3. *Myzus persicae* (Green peach aphid) (Hemiptera: Aphididae)

2.5.3.1 General morphology and taxonomic identification

The green peach aphid belongs to family: Aphididae and genus *Myzus*. It was first described by Sulzer in 1776 as *Aphis persicae*. Its numerous synonyms are listed by Börner (1952) and Remaudiere (1997) and its taxonomy was reviewed by Blackman and Paterson (1986) and Blackman and Eastop (2007). Two forms occur which includes; the apterae (wingless) and the alatae (winged). The Apterae vary from whitish or pale yellowish green to mid-green, rose-pink or red, rather uniformly coloured, not shiny, often darker in cold conditions, with a body length of 1.2-2.3 mm. They have a tapering, unswollen siphunculi. Winged (alate) aphids have a black head and thorax, and a yellowish green abdomen with a large dark patch dorsally. They have a body length of 1.8 to 2.1 mm and the immature are often pink or red (Blackman and Eastop, 1984). The antennae and cornicles of the green peach aphid are the same color as the body, but slightly darker at the end. It differs from other aphid species found on crucifers in that the antennal tubercles are prominent and pointed inward, and the cornicles are swollen near the base and are longer than the cauda. Nymphs are similar to adults in shape and colour but are smaller.

2.5.3.2 Origin and distribution

Myzus persicae is probably of East Asian origin like its primary host plant (*Prunus persica*), but is now world-wide except where there are extremes of temperature or humidity (CIE, 1979). It is also found in all areas of North America, where it is viewed as a pest principally due to its ability to transmit plant viruses (Smith and Cermeli, 1979; CIE, 1979).

Plate 2: Green peach aphid, *Myzus persicae* Sulzer (Photo taken by Ethelyn Echep Forchibe).

2.5.3.3 Host status and specificity

The winter (primary) host of *M. persicae* is almost invariably *Prunus persica* (peach), including var. *nectarina*; sometimes *P. nigra* in USA, and possibly *P. tenella*, *P. nana*, *P. serotina*, *P. americana* and peach-almond hybrids (Shands *et al*., 1969; Retan and Thornton, 1982). However, *M. persicae* is highly polyphagous on other host plants in summer. It has over 400 species of plants as hosts which are in over 40 different families, including Brassicaceae, Solanaceae, Poaceae, Leguminosae, Cyperaceae, Convolvulaceae, Chenopodiaceae, Compositae, Cucurbitaceae and Umbelliferae (Cloyd and Sadof, 1998). These host plants are of great economic importance. The green peach aphid is an important pest on crucifers and other leafy vegetables because, it is highly efficient as a plant-virus vector and is one of the most widespread insect pests, as it has been recorded on all continents where crops are grown (Cloyd and Sadof, 1998; Blackman and Eastop, 2000).

2.5.3.4 Biology and ecology

Myzus persicae is heteroecious holocyclic (host alternating, with sexual reproduction during part of life-cycle) between *Prunus* (usually peach) and summer host plants, but anholocyclic on secondary (summer) hosts in many parts of the world where peach is absent, and where a mild climate permits active stages to survive throughout the winter (Broadbent, 1949; Blackman, 1974). It is usually anholocyclic in tropics and sub-tropics, with exceptions: for example, Ghosh and Verma (1990) reported apterous oviparous females of *M. persicae* for the first time from India, collected on *Prunus persica* (Blackman, 1974) In the warmer months, and throughout the year in warmer climates, the green peach aphid reproduces asexually; adults produce nymphs on a wide variety of herbaceous plant material, including many vegetable crops such as cabbage and its *Brassica* relatives, potato and other crops of the family solanaceae, celery, mustard, pepper, pumpkin, okra, corn, and sunflower and other flower crops (Blackman, 1974; Margaritopoulos *et al*., 2002). An individual can reproduce twelve days after being born and there may be twenty generations over the course of a year in warmer areas. As the weather cools, aphids mate and lay their tiny (0.6 mm x 0.3 mm) oval eggs in crevices of the bark of *Prunus* trees (Blackman, 1972)

2.5.4 *Lipaphis erysimi* (The mustard aphid) (Hemiptera: Aphididae)

2.5.4.1 General morphology and taxonomic identification

Lipaphis erysimi (Kaltenbach) belongs to family: Aphididae and genus *Lipaphis.* These apterae are yellowish green, dirty green or brownish with a body length of 1.5-2.3 mm. They are varying shades of green and have slightly darker spots on the dorsal surface of the abdominal segments in front of the cornicles. Winged females have dusky green abdomens with dark lateral stripes (Blackman and Eastop, 1984). The antennae are also dark, except at the base (Deshpande, 1937).

These aphids have a slightly visible thin layer of white, waxy secretions (much less than the cabbage aphid). Their major distinguishing characteristics from other aphids are the frontal tubercles do not converge; the cornicles are not dark and are longer than the cauda; the cauda is tongue-shaped; and colonies have a thin layer of white, waxy secretion (Blackman and Eastop, 1984).

Plate 3: Mustard aphid, *Lipaphis erysimi*, Kaltenbach (Photo taken by Ethelyn Echep Forchibe)

2.5.4.2 Origin and distribution

The turnip or mustard aphid has a worldwide distribution (Blackman and Eastop, 1984). Records in literature report this aphid has been found in several countries in Africa including Mali, Kenya, Benin and South Africa (Daiber, 1971; Liu et al., 1997; James *et al*., 2010; Sæthre *et al*., 2011).

2.5.4.3 Host status and specificity

This pest is widely distributed throughout the world on all Brassica crops (Yue and Liu, 2000; Alavo and Abagli, 2011).

2.5.4.4 Biology and ecology

This aphid has two modes of reproduction: fertilization of females by males resulting in the production of eggs (sexual reproduction), and by giving live birth to female nymphs without fertilization (parthenogenesis). Reproduction through parthenogenesis seems to be common as males are very rare and females are almost exclusively viviparous throughout the year and males have only been observed in the cooler months (Kawada and Murai, 1979). Its longevity depends crucially on temperature. Within the viable temperature ranges, high temperatures shorten the life span and cooler temperatures increase longevity (Sidhu and Singh, 1964). It has also been reported that the fecundity of the Turnip aphid is not only influenced by the species and variety of the host plant but also by temperature (Singh, *et al.*, 1965).

2.6 Economic importance of aphids

Aphids are destructive pest in all areas where cabbage is grown (Bhatia and Verma, 1994; Dattu and Dattu, 1995), causing severe losses in cruciferous crop production, by reduction of yield and marketability (Liu *et al.*, 1994; Costello and Altieri, 1995). Generally, aphids have piercing and sucking mouthparts, which they use to suck sap from their host plants. The damage caused by aphids to cruciferous crops, can be direct or indirect damage. Direct damage can be caused by both adults and nymphs; with their mouthparts, they attach to their host plant tissues and suck sap from them, depriving them of nutrients. This leads to weak, wrinkled leaves that are cupped outward and inward, resulting in a deformed plant with lower yields (Hughes, 1963; Mochiah *et al.*, 2011). The wrinkled leaves later become wilted, distorted or yellowish when the population of the aphids increases. Their feeding also leads to stunted growth, and eventually death of the plant, and sometimes unmarketable heads (Behdad, 1982; Griffin and Williamson, 2012). Indirect damage from aphid feeding results from the excreta (honeydew) that supports the growth of sooty mould (Hughes, 1963; Dubey *et al*., 1981) and also transmission of viral diseases such as Tulip Mosaic Virus (TMV) (Blackman and Eastop 2000; Schliephake *et al*., 2000; Parker *et al*., 2003).

The cabbage aphid, *Brevicoryne brassicae* L. (*Aphidae*), infests crucifer plants in temperate areas all over the world (Ellis and Singh, 1993; Shaltiel and Ayal, 1998). It is considered one of the most damaging and consistently present pests on cabbage crops (Theunissen, 1989). *Brevicoryne brassicae* causes direct damage, resulting from searching for food, which may induce plant deformation (Ibbotson, 1953; Oatman and Platner, 1969). The cabbage aphid causes indirect damage to cabbage either by producing honeydew or by transmission of viruses. It is known to be a vector of about 23 viral diseases of Crucifers (Flint, 1991). It transmits the Tulip Mosaic Virus in cabbage (Dubey *et al*. 1981; Costello & Altieri 1995; Chivasa *et al*., 2002).

The mustard aphid; *Lipaphis erysimi* (Kaltenblach) causes damage to cruciferous plants at all growth stages (Goggin, 2007). In addition, the mustard aphid is a vector of about 10 plant viruses that cause greater yield losses

(Blackman and Eastop, 1984). It has been shown to transmit about 13 different viruses, including important viruses of the Brassicaceae, such as Beet mosaic virus, Cabbage black ring spot virus, Cauliflower mosaic virus, and Radish mosaic virus (Kennedy *et al*., 1962). This pest is widely distributed throughout the world on all Brassica crops (Yue and Liu, 2000) and responsible to cause yield loss ranging from 9 to 96% (Singh and Sharma 2002) and 15% oil reduction (Verma and Singh 1987) in India. Bakhetia (1987) and Narang *et al.* (1993) reported the mustard aphid as the most serious pest in canola, causing severe damages of up to 90%. Khajehzadeh and Kariminezhad (2008) also reported that the average yield loss caused by the mustard aphid was up to 27%.

Direct feeding damage by *M. persicae* can result in stunted growth and reduced root weight, but populations on most crops do not reach levels causing obvious symptoms such as chlorosis or leaf curling, and the production of honeydew with associated sooty mould formation (Blackman and Eastop, 2000). *Myzus persicae* is the most important aphid virus vector. It has been shown to transmit well over 100 plant virus diseases, in about 30 different families, including many major crops. Some persistent and non-persistent viruses transmitted include potato leaf roll virus and cuccumber mosaic virus, respectively and several other viruses (Eskanderi *et al*., 1979; Bwye *et al*., 1997). Even at low populations, aphids have a negative effect on the growth, yield and quality of the crops.

2.7 Management of aphids on cabbage

Aphids are regarded as one of the most economically important pests in cabbage cultivation because they easily become resistant to insecticides (Abramson *et al*., 2006). Until now several control methods have been employed to control them and are as follow;

2.7.1 Cultural control

Before the advent of synthetic insecticides, insect pest control was dependent on cultural control methods. Recently, because of failure of insecticides to control most insect pest on cabbage and its side effects, there has been a keen interest in cultural control in commercial cabbage production. Below are some cultural control practices used for pest management.

2.7.1.1 Farm sanitation

Aphid infestation on cabbage fields can be greatly reduced by practicing farm sanitation and clean cultivation. Fields should be ploughed immediately after harvest to prevent the spread of aphids to other crops (Griffin and Williamson, 2012). It is important to rid the field and surrounding areas of any alternate host plants like mustards or other cruciferous weeds (Natwick, 2009). Destruction of plant debris at the end of the season can help kill overwintering aphid eggs in temperate climates (Hines and Hutchison, 2013). Replanting on land where an aphid-infested crop has been recently removed is not advisable, as this will lead to carry-over of pests (Razaq *et al*., 2012).

2.7.1.2 Crop rotation

Crop rotation with non-host crops is also beneficial in insect pest control (Kessing and Mau, 1991). It is a method in which different crops are planted on a piece of land every farming season. This method of farming reduces build-up of a particular pest, and improves soil fertility especially when leguminous crops are incorporated in the cycle.

2.7.1.3 Trap cropping

Trap cropping is the planting of an attractive crop to protect the main cash crop from a certain pest or several pests. The trap crop can be from the same or different family group, other than that of the main crop, as long as it is more attractive to the pest (Hokkanen, 1991). Webb, (2010) reported that beneficial insects were attracted when sweet alyssum (*Lobularia maritima* (L.) Desv.) a nectar plant, was used as a trap crop in a cabbage field. Effective trap cropping also helps to eliminate excessive use of insecticides because the pest will be retained in the trap crop and become heavily parasitized (Talekar and Shelton, 1993). FAO (1990) also reported a reduction in damage caused by insect pest when crops like white mustard (*Brassica hirta*) and rape (*Brassica juncea*), were used as trap crops in cabbage.

2.7.1.4 Intercropping

Intercropping is a method of farming that involves the cultivation of two or more crops simultaneously on the same field (Björkman, 2007). Intercropping is highly efficient in reducing insect pest populations because it acts as a physical barrier to movement of insect pest as well as disrupting chemical or visual stimuli between the insect pest and their host plant (Sheehan, 1986). Ponti *et al*. (2007) in a study of broccoli and mustard observed a high parasitization of cabbage aphids by *Diaretiella rapae* (McIntosh) (Hymenoptera: Braconidae) during summer. Mochiah *et al*. (2011a) in a related work in Ghana showed that cabbage intercropped with tomatoes was effective in reducing the number of insect pests on cabbage. Intercropping cabbage with onion was effective against key pests such as the diamondback moth and the cabbage webworm (Oseifuah, 2015).

2.7.2 Use of chemicals

Production of healthy and damage free vegetables especially cabbage for the wealthy urban population and the international market is of outmost concern, and an important consideration in all farming practices, especially plant protection (Talekar and Shelton, 1993). To achieve this, most farmers use insecticides because they believe it gives rapid results (Ntow *et al*., 2006; Essumang *et al*., 2008; Armah, 2011; Bempah *et al*., 2011; Owusu-Boateng & Amuzu, 2013). In Ghana, several insecticides are used on cabbage, against insect pests and these include: Dursban (Chlorpyrifos), Ambush (permethrin), Actellic (pirimiphos-methyl), Attack (Emamectin benzoate), Bossmate (lambda-cyahalothrin), Roxion (dimethoate), Cymbush 25 EC (Brempong-Yeboah, 1992; Mawuenyegah, 1994; Fening *et al*., 2013). Karishniah and Mohan (1983) reported that chlorpyrifos gave effective control and suppressed the population of mustard aphid. Jansson *et al*. (2012) reported that Emamectin benzoate was very effective against lepidopterous pests, with a minimal effect on the beneficial insects.

However, over the years, synthetic pesticides have been realised to have negative effects which includes: destruction of non-target organisms such as beneficial insects (pollinators and natural enemies); contamination of farm produce with insecticide residues; exposure of the user to risks of chemical poisoning; environmental contamination and development of insecticide resistance (Obeng-Ofori *et al*., 2002; Timbilla and Nyarko, 2004; Ntow *et al*., 2006; Fening *et al*., 2011, 2013, 2014). A study in Pakistan reported resistance of cabbage aphids to methomyl, emamectin benzoate, pyrethroids (cypermethrin, lambda cyhalothrin, bifenthrin and deltamethrin) and neonicotinoids (imidacloprid, acetamiprid, and thiamethoxam). Their level of resistance was also found to increase progressively in concurrence with regular use on vegetables (Ahmad and Akhtar 2013). Rabea (2009) reported resistance of *M. persicae* to chlorpyrifos, lambda-cyhalothrin profenofos, spinosad and deltamethrin. Fernandez *et al*. (2010) and Devotto *et al*. (2007) reported that organophosphates and pyrethroids are broad spectrum insecticides, and are known to be highly toxic to predators. Chlorpyriphos 20% EC, was found to be highly toxic to the maggots of *Ischiodon scutellaris* (Boopathi and Pathak, 2011). Fenning *et al*., 2013, reported adverse effects on natural enemies by lambda-cyhalothrin, leading to continuous build-up of pests on cabbage.

All these are major setback for insecticide use; as such, alternative approaches to managing pests of cabbage and other vegetables must be sought, to obtain sustainable control (Ntow *et al*., 2006; Coulibaly *et al*., 2007; Fening *et al*., 2014).

2.7.3 Insecticidal soaps

Insecticidal soaps are composed of potassium salts of several fatty acids whose mode of action is not well understood but it is believed to disrupt pest's cellular membrane especially soft bodied insects resulting to loss of cellular contents, hence, death (Osborne and Henley 1982). The solution of these soaps can be an effective remedy to control aphids. Control of aphids with insecticidal soap have been reported by Flint, 2013; Cranshaw, 2008; Ubl, 2009. Soap sprays will only kill aphids on contact and has no residual action against aphids that arrive after application. They may also damage plants if used at high concentrations (Organic Resource Guide, 2010).

2.7.4 Plant resistance

Plants respond to herbivore attack through an intricate and dynamic defense system that includes structural barriers, toxic chemicals, and attraction of natural enemies of the target pests (Hanley *et al*., 2007; Howe and Jander, 2008; Karban, 2011). Plant structural traits such as trichomes have been shown to release a sticky exudate, which immobilizes aphids. Increased waxiness in brassicas decreased aphid colonization, mainly due to a non-preference resistance mechanism (Stoner, 1992). Jahan *et al*., 2013 concluded that the cauliflower cultivar 'Smilla' is a good choice because it affects adult reproductive parameters of aphids. In India, some rape and brussel sprouts were identified to be resistant to cabbage aphid (Pakhraj *et al*., 2005). Therefore, choice of cultivar could reduce aphid populations and damage.

2.7.5 Use of pheromones

Pheromones are chemical substances (messengers) that are released by species specific insects for communication (Vet and Dicke, 1992). Gabrys *et al*. (1997) indicated that the sex pheromone

(4aS,7S,7aR)-nepetalactone proved to be effective in laboratory bioassay by increasing the catches of the males of *B. brassicae* when it was released from glass vials placed above water traps in crops of autumn brassicas. In addition, larger populations of parasitoids of *B. brassicae* were found in pheromone traps. Therefore, use of pheromones is a promising method for control of aphids.

2.7.6 Use of botanicals

Botanicals are plant extracts that are toxic to insects through contact, respiratory or stomach poison due to the presence of certain compounds such as secondary metabolites which they contain (Kareru *et al*., 2013). Extracts and essential oils of certain plants have been used to protect crops against attack for ages because they have proved toxic to some economic important insect pests (Isman, 2000, 2002; Belmain and Stevenson, 2001; Koul, 2004; Regnault-Roger *et al*., 2005; Isman, 2008). Extracts from locally available plants used traditionally have proved to be very effective as crop protectants in Africa and have been successfully used against a number of agricultural pests (Barbouche *et al*., 2001; Isman, 2008; Kareru *et al*., 2013). They are capable of managing insecticide-resistant pests of many crops (Amoabeng *et al*., 2013). Botanicals are often regarded as safe to humans, animals and the environment because of their specificity and non-persistent nature (Charleston *et al*., 2006' Dubey *et al*., 2011). Isman (2006) stated that, the complex terpinoid azadirachtin, derived from the seeds of the the indian neem tree *Azadirachta indica*, is a potent insect growth regulator and feeding deterrent, with very low mammalian toxicity and environmental persistence. In Ghana, work by Obeng-Ofori (2008) using crude seed extracts of neem was effective against insect pests of tomato, cabbage, cucumber, okra, pepper and garden eggs. Srivastava and Guleria (2003) reported thirty-four plants with insecticidal activity against *L. erysimi*. They further reported that, extracts of *Azadirachta indica* (Neem) and *Chrysanthemum*, recorded highest mortality of *L. erysimi*. Nguyen *et al*. (2014) reported that garlic and chili combination solution had a positive effect on pest reduction in a cabbage field. Aline and Mauricio (2015), reported effective control of the cabbage aphid on kale using neem oil and kaolin oil. Prasannakumar *et al*., (2014) observed effective control of *H. undalis* and aphids when cabbages were treated with neem seed powder extract and neem soap. Fening *et al*. (2011) demonstrated the potential of low doses of garlic and hot pepper in the management of insect pests of cabbage while conserving their natural enemies. Habimana and Hakizayezu (2014) reported that, alkaloids from chilli controlled aphids 100%. Lidet *et al*. (2009) reported improved cabbage yield when neem was used against insect pest. Use of *A. indica* seeds and *Lanthana camara* leaf extracts in cabbage fields, increased yield by 37.05% and 25.80%, respectively, with a significant reduction in the number of pests (Baidoo and Adam, 2012). Dzomeku *et al*. (2011) reported that Neem seed extract was highly effective in protecting cabbage plants against insect pests leading to high yield quality compared to Karate (Lambda-cyhalothrin) and water.

Botanical insecticides can provide realistic alternatives to chemical insecticides because of their safety to the user and the wider ecosystem (Rechcigl and Rechcigl, 2000; Buss and Park-Brown, 2002). Unlike synthetic insecticides, botanical insecticides are natural and easily degradable in the eco-system upon exposure to sunlight, air and moisture (Buss and Park-Brown, 2002; Dubey *et al.*, 2011).

2.7.7 Biological control

Biological control involves the use of natural enemies; microbials, predators and parasitoids to control insect pests. Generally, natural enemy populations are often numerous enough to keep aphid infestations below economic levels (Rabasse and van Steenis, 1999; Mandal and Patnaik, 2008). In some cases, wasp parasites are the most effective; in other cases, predators, especially syrphid flies, or weather conditions and fungi causes the most mortality (Furlong, 2004; Duchovskiene *et al*., 2006; Chakrabarti *et al*., 2012; Liu *et al*., 2014). Protecting the habitat that will foster the population and survival of natural enemies can help reduce the need for pesticides (Natwick, 2009).

2.7.7.1 Predators

Among the polyphagous predators able to feed on aphids, the most common and predominant are the Syrphidae (syrphid or hover fly larvae), coccinellidae (Lady bird beetles, larvae and adults) and other predators (lacewings, midges and several species of spiders) which are often effective in destroying aphids, especially small colonies (Liu et al., 2014; Duchovskiene et al., 2006). These predators sting and suck the body contents of soft-bodied aphids leading to death.

2.7.7.1.1 Hoverfly

Hoverflies also known as Syrphid flies are stingless and hover around, have black and yellow bands on their abdomen and often confused with honeybees. There are several hoverfly species and larvae of predaceous species feed on aphids and other soft-bodied insects thus, play an important role in suppressing populations of phytophagous insects (Bugg *et al*., 2008). Hoverfly larvae are legless maggots with flattened, relatively broad bodies up to 12mm long. They often have semi-transparent bodies so internal structures, such as the gut, can be seen. Pupae are oblong, pear-shaped, and green to dark brown in color. Pupation occurs on plants or on the soil surface (Hoffman and Frodsham, 1993; Bugg *et al*., 2008). The larvae move along plant surfaces, lifting their heads to grope for prey. They suck up fluids from their bodies, later discarding the skins.

Hoverflies have been found to be very effective in suppressing aphid populations in gardens and mixed plots. They will be most noticeable in the latter half of the growing season, usually after aphid infestations are established (Hoffman and Frodsham, 1993).

Plate 4: Hoverfly, *Paragus borbonicus* (larva, pupa and adult) (Photo taken by Ethelyn Echep Forchibe).

2.7.7.1.2 Ladybird beetle

Coccinellidae is a well-known beetle family, worldwide distributed and divided into six subfamilies: Coccidulinae, Coccinellinae, Scymninae, Chilocorinae, Sticholotidinae and Epilachninae (Vandenberg, 2002). Except for the mycophagous Coccinellinae (Halyziini and *Tythaspis*) and the phytophagous Epilachninae, all remaining coccinellids are predators of hemipteran insects (*e.g*. aphids, scales, psyllids and whiteflies), mites and eventually other insect larvae (Dixon, 2000). The Coccinellidae are a family of small beetles, ranging from 0.8 to 18 mm (Seago *et al*., 2011; Pandi *et al*., 2012). They are commonly yellow, orange, or scarlet with small black spots on their wing covers, with black legs, heads and antennae (Seago *et al*., 2011; Pandi *et al*., 2012). Predatory coccinellids are usually found on plants which harbour their prey. They lay their eggs near their prey, to increase the likelihood of the larvae finding the prey. Both adults and larvae feed on aphids (Omkar *et al*., 2009).

Plate 5: Ladybird beetle, *Coccinella* sp. (larvae, pupa, adult). (Photo taken by Ethelyn Echep Forchibe).

2.7.7.1.3 Spiders

Spiders (Class Arachnida, order Araneae) are air-breathing arthropods that differ anatomically, from other arthropods in that the usual body segments are fused into two tagmata, to form the cephalothorax and abdomen, joined by a small pedicel (Sebastin and Peter, 2009) (Plate 6). Spiders are general predators and they kill their prey by injection of venom. They are considered the largest number of invertebrate predators in terrestrial habitats (Quan *et al*., 2011). They are important predators of pests on cabbage in the field (Zhao, 1995; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014). They hunt or use webbing for catching of prey (Dippenaar-Schoeman *et al*., 2013; Ghoneim, 2014).

Plate 6: Some spiders present on cabbage (Photo by Ethelyn Echep Forchibe).

2.7.7.2 Parasitoids

All aphid parasitoids are solitary endoparasitoids and belong to the family Braconidae in the order Hymenoptera (Hagvar and Hofsvang, 1991).

2.9.7.2.1 *Diaeretiella rapae*

Diaeretiella rapae (McIntosh) (Hymenoptera: Braconidae) is a small aphidiid wasp (Plate 7) and has played a significant role in preventing aphid outbreaks in cruciferous crops (Desneux *et al.*, 2005).

Plate 7: *Diaeretiella rapae* (McIntosh) (Hymenoptera: Braconidae) (Source: ponent.atspace.org [Assessed, January 04, 2016)

It is a cosmopolitan endoparasitoid of a wide range of aphid species on a number of host plants (Elliott *et al*., 1994; Pike *et al.*, 1999). The adult female is dark brown, 3 mm long and deposits an average of 85 eggs internally in separate aphids over a lifetime (McIntosh, 1855; Stary, 1999). The larvae of the wasp consume the body contents of aphids, and when fully grown, the empty bodies of the host aphids turn into hardened, light brown shells called mummies. The adult wasp emerges through a circular hole cut in the back of the mummy (Singh *et al*.,1999; Desneux *et al.*, 2005). In cruciferous vegetable fields, the number of *D. rapae* amounted to 82.5% of all aphid parasitoids collected in the USA (Pike *et al*., 1999). In cabbage fields in Poland, the percent parasitism of cabbage aphids by naturally occurring *D. rapae* was about 35%, 2 weeks after initial parasitism; the number of parasitoids was low in early season, and the natural population of *D. rapae* could not control the aphid population (Gabrys *et al*., 1998).

CHAPTER 3

3.0 MATERIALS AND METHOD

3.1 Study area

The research was carried out at the Soil and Irrigation Research Centre, Kpong (00 04' E, 60 09' N), in the Eastern region of Ghana, found in the Coastal Savanna agro-ecological zone. It is part of the Accra plains (Plate 8) and has annual rainfall between 700 and 1100mm. It is characterized by an average annual temperature of 28 ˚C, relative humidity between 59%-93%. The main soil type is the Akuse series (Amatekpor *et al.*, 1993) or Vertisols (black clay soil) with the potential for irrigation (due to the presence of the Volta lake) to allow all-year round vegetable production. The main occupation of inhabitants in this area is farming and fishing.

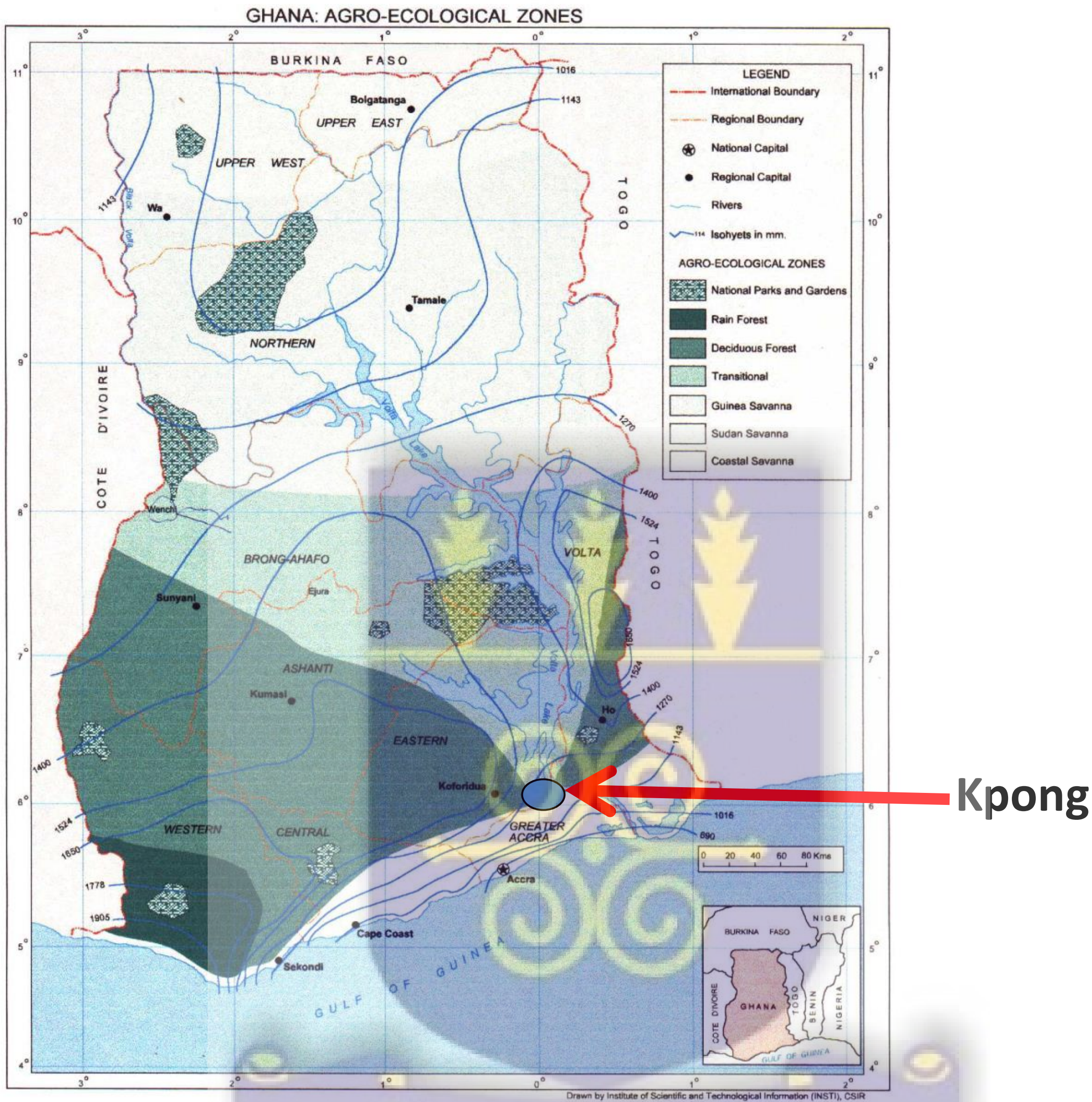


Plate 8: Map showing study area (source: Koomson, 2013).

3.2 Experimental design

The experimental field was laid out following a complete randomized block design with three replications or blocks. Each block consisted of 6 treatment plots, giving a total of 18 plots in total. The area per plot was 3 x 3m. Inter-plot distance was 1.5m while inter-block distance was 2m.

3.2.1 Treatments

There was a total of 6 treatments consisting of two synthetic insecticides (chlorpyrifos (CONPYRIFOS®) and lambda cyhalothrin (LAMBDA-M®), two botanicals (neem seed extract and hot pepper extract), alata samina solution (local soap) and control (Plate 9). The two synthetic insecticides were choosen because baseline study showed that these chemicals are often used by farmers on cabbage fields (Fening per. comm). The botanicals are locally available plants, which have been reported to have insecticidal properties in other areas. Soaps are known to have insecticidal properties, reason why alata samina was choosen to confirm its action. Treatments were applied according to recommended rates (Table 4), and there were three replications for each treatment plot.

Table 4: Treatments used, description and application rates.

Treatment	**Chemical group**	**Description**	**Application rate**
Control	Neutral	Water	204L/ha
Hot pepper *(Capsicum frutescens)*	Botanical	Aqueous fruit extract	20g/L of water (4.08kg/ ha)
Neem *(Azadirachta indica)*	Botanical	Aqueous seed extract	50g/L of water (10.20kg/ha)
Alata samina	Botanical	Local soap made from cocoa husk	6g/L of water (1.22kg/ha)
Lambda cyahalothrin (LAMBDA-M®)	Synthetic insecticide	a pyrethroid insecticide	2ml/L of water (4.08L/ha)
Chlorpyrifos (CONPYRIFOS®)	Synthetic insecticide	An organophosphate insecticide	2ml/L of water (4.08L/ha)

Plate 9: Spray formulations utilized in field trial

3.3 Land preparation, nursery establishment and transplanting of seedlings

3.3.1 Land preparation

Land for experimental plots were cleared of weeds, ploughed, harrowed and ridged in May 2015. Ploughing and harrowing were done to break and loosen the clayey soil. Ridges were made with a ridger to allow for proper irrigation of the fields and good flow of water through the furrows. Each plot consisted of five ridges. Each plot was 3m x 3m.

3.3.2 Nursery establishment

Disease free certified healthy hybrid white cabbage (*B. oleracea* var. *capitata*) (cv. Oxylus) were purchased from AGRI-MAT Limited, Accra, Ghana. Nursery beds demarcated; 5m x 1m were tilled with hoes, and decomposed poultry manure (25t/ha) was mixed with the soil and allowed for one week before sowing of seeds. This was done to prevent heat generated by microbes in the manure from destroying the seeds, and also for complete decomposition of manure. Seeds were sown on the nursery beds on the 24th of May 2015 and 28th of September 2015 for the major and minor seasons, respectively. The nursery beds were shaded from the sun using pest-free palm branches raised on wooden sticks (60 cm high). When the seeds germinated the young seedlings were protected from attack by insect pests with a mosquito-proof net (1.2 mm×1.2 mm of mesh size) (Plate 10). Cultural practices such as hand picking of weeds, thinning out and watering were carried out as regularly as the need arose.

Plate 10: Cabbage in the nursery (major season).

3.3.3 Transplanting of seedlings

Cabbage seedlings were transplanted four weeks after germination. The experimental field was irrigated before transplanting was done. Healthy seedlings with about six true leaves were selected for transplanting to ensure good survival and uniform establishment of the crops. The seedlings were transplanted 2cm deep into the soil. The planting distance within and between the cabbages on the plots was 50cm × 75cm, giving a total of 30 cabbages per plot. Plots were labeled by randomly assigning treatment to them. White boards were used for labeling treatment plots (Plate 11). NPK 15-15-15 (5g/plant) and Sulphate of Ammonia (3g/plant) were applied into the soil 10 and 42 days, respectively, after transplanting, applied in a ring form around each plant during each cropping season.

Plate 11: Cabbage plants on the field (major season).

3.3.4 Weed control and watering (irrigation)

Generally, weeds compete with field crops for essential components such as sunlight, space and soil nutrients. Weeds were controlled using hoes and were done when weeds were observed in the field. Irrigation was carried out every week using irrigation pipes, as when necessary.

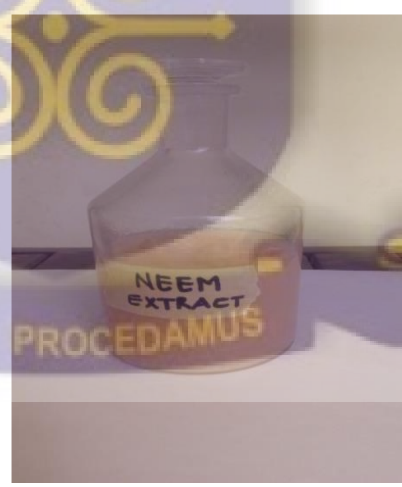
3.4 Preparation of treatments

Synthetic chemicals were prepared mixing the appropriate quantity in the required volume of water. Botanicals were prepared following a series of steps as described below.

3.4.1 Neem seed extract preparation

Freshly fallen neem seeds were collected from underneath neem trees and placed in an airy bag to prevent the formation of mould. The seeds were dried further by placing them in the shade. When needed, 50g of neem seeds were crushed in a mortar. The crushed seeds were later mixed with one litre of water and stirred. Two drops of liquid soap and oil were added to the mixture and allowed to stand overnight (Plate 12). The mixture was then filtered, poured into a 15L knapsack and sprayed onto the cabbage plants.


A



B

Plate 12: Neem seeds (A) and aqueos neem seed extract (B).

3.4.2 Pepper extract preparation

Riped fruits of red hot pepper; *Capsicum frutescens* were collected and 20g were measured using an electronic scale. The 20g of pepper was placed in a blender and 200ml of water was added (Plate 13). The mixture was blended for five minutes to give a fine and uniform mixture. About 800ml of water was then added to makeup one litre. Two drops of liquid soap and oil were added to the mixture and allowed to stand overnight. The mixture was filtered into a 15L knapsack and sprayed unto plants.

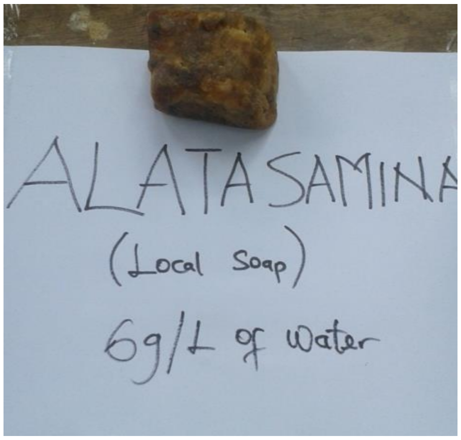
A

B

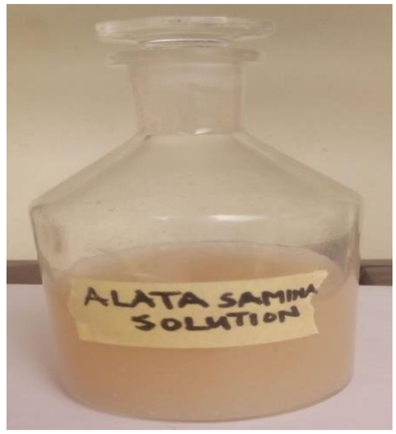
Plate 13: Red hot pepper fruit (A) and extract (B).

3.4.3 Preparation of soap spray

About 6g of alata samina (local soap) was measured and dissolved in a litre of water, to make a soap spray (Plate 14). The soap solution was sprayed to the plants using a 15L knapsack.



A



B

Plate 14: Alata samina (A) and solution (B).

3.5 Application of treatments

Treatments were applied 14 days after transplanting of cabbage seedlings. Two knapsacks were used to apply the treatments; one for botanicals and the other for synthetic insecticides. All treatments were applied in the evening to prevent photo-breakdown of chemicals. After application of one treatment, spray equipments were thoroughly washed before application of the next one. Spraying was repeated weekly until the cabbage heads were fully matured, about 14 days to harvesting.

3.6 Sampling and data collection

Data was collected weekly, three days after application of treatments, and up to two weeks before harvesting for both the major and minor cropping seasons, 2015. The following data were collected: number of aphids per plot, number of natural enemies per plot, abundance of other insect pest of cabbage, multiple heads formation, incidence and severity of ‘suspected’ viral disease, cabbage yield per plot and number of cabbage heads with holes. Plants from the inner rows were used for assessing pests/natural enemy counts, damage and yield. All plants per plot were considered when assessing the disease incidence and severity. Ten plants were selected randomly from the inner rows for sampling of aphids. All plants in the inner rows were sampled for yield. Weather data for the period of the experiment was collected from the Soil and Irrigation Research Centre weather station.

3.6.1 Sampling of aphids from cabbage and their natural enemies

Sampling of aphids, were modified from method according to Hughes, 1963. Ten leaves were harvested weekly from ten randomly selected plants in the inner rows in each plot, and placed in labeled envelopes. The ten leaves were placed into 70% alcohol to wash off aphids from the leaves into the solution. The solution was later poured into petri dishes for counting. During counting, aphid samples were separated from other associated insects, such as, lepidopterous larvae (hoverfly, diamondback moth etc.), and various aphid predators (ladybirds, spiders, etc.). The number of the predators were counted and recorded as well as the number of aphids. The number of aphids with wings (alates) were also counted. Aphids were sorted into two groups (the pink and the green forms) before counting. Also the number of mummified aphids were recorded to determine the parasitism rate by the main aphid parasitoid; *D. rapae*. Field observations were made weekly to determine the numbers of natural enemies per plot. Aphid and natural enemy samples were collected into vials using the camel hair brush and forceps, and then preserved in 70% and 96% alcohol for further identification.

3.6.2 Sampling for other insect pest

Plants in the inner rows were sampled weekly for the abundance of other insect pests on cabbage. The plants were checked and any insect observed, were counted and recorded following methods used by Fening *et al*., 2011, 2013, 2014.

3.7 Damage assessment

3.7.1 Leaf damage assessment

Leaf damage such as multiple heads were counted per plot and recorded. The percentage multiple heads formed was calculated by dividing the number of plants with multiple heads by the total number of plants and multiplied by 100%. That is:

$$\frac{Number\ of\ plants\ with\ multiple\ heads}{\text{Total number of plants per plot}} \times 100 = \text{Percent multiple head formation.}$$

3.7.2 Disease incidence and severity

3.7.2.1 Disease incidence

Field observations were made two times and the number of cabbage plants with symptoms of the 'suspected' viral disease were counted and recorded per plot. The disease incidence per plot was calculated by taking the average of the two observations, divided by the total number of plants, multiplied by a hundred. This can be given as follows;

$$\text{Disease incidence} = \frac{number\ of\ infested\ plants}{total\ number\ of\ plants} \times 100$$

3.7.2.2 Disease severity

Severity or level of disease infestation was undertaken by using a scoring scale from 1-5 depending on the intensity of symptoms present and damage caused (where 0 = no symptoms and 5 = severe damage symptoms (lITA 1990; Okechukwu and Dixon, 2009; Fening *et al*., 2014) (plate 15). Three plants were randomly selected from the inner rows per plot and scored for disease severity.

3.8 Harvesting of cabbage heads for yield

The cabbage heads were harvested after 3½ months, two weeks after last treatment application. All cabbage plants from the inner rows were harvested by cutting the cabbage heads for each plot. The cabbage heads were weighed using a salter balance (plate 16) and the weights (g) were recorded. The yield per unit area was extrapolated into tons per hectare (ton/ha) and this is given by;

$$\text{Yield} = \left[\frac{area\ of\ hectar\ (10000m2)}{area\ of\ harvest\ per\ plot} \times total\ yield\ per\ plot(kg)\right]/1000$$

Plate 15: scale for weighing cabbage heads

3.9 Yield quality assessment

Harvested cabbage heads were checked for holes and insect damage. The heads were examined for deep holes created by insect pests. Cabbage head damage was assessed by using a standard scoring scale of 0-5 (Aboagye, 1996). 0= no head damage, 1= 1-15% head damage, 2= 16-30% head damage, 3=31- 45% head damage, 4= 46-60% head damage, 5= 61-100% head damage. The harvested heads were marked as marketable and unmarketable (Plate 17), and their percentages calculated for each treatment and cropping season.

A B

Plate 16: Marketable (A) and Unmarketable head (B).

3.10 Insects identification

3.10.1 Aphid identification

3.10.1.1 Sample collection, processing and morphological identification

Individual aphids, both winged and wingless adults, were collected on cabbage plants from SIREC, Kpong, Ghana in August 2015, with part stored in 96% ethanol at 4°C, and another part in RNA *later* (Qiagen, Hilden, Germany) at -20°C, until identification was carried out using morphological examination and molecular genetic analysis. For morphological examination, a Leica EZ4 D stereomicroscope with 40× magnification was used to identify the specimens following the keys of Blackman and Eastop (1985).

3.10.1.2 Molecular genetic analysis

DNA extraction

Confirmation of aphid identity was done by sequencing of the *Cytochrome c oxidase subunit I* (*CO I*) gene. A 'TRIzol-like' extraction buffer [made up of 38% v/v Tris-buffered phenol. 0.8 M guanidine thiocyanate, 0.1 M sodium acetate pH 5.0, 5% (v/v) glycerol] was used for nucleic acid extraction. A single aphid was put into a 1.5 ml microfuge tube and 150µl TRIzol extraction buffer added. It was ground using a micro pestle and 15µl chloroform isolamyl alcohol (24:1) added and the mixture vortexed well. The mixture was incubated on ice for 5 minutes then centrifuge at 10000 Xg for 5 minutes. The aqueous phase was transferred to a fresh microfuge tube (Approximately 100 µl) and d 1:10 volume of sodium acetate (10 µl) added followed by 2 volumes (200 µl) pre-chilled absolute ethanol. The mixture was mixed gently by inverting the microfuge tubes then incubated at -20 degrees for 2 hours. After this the mixture was centrifuged at 10000 Xg in a pre-chilled centrifuge for 15 minutes. The resulting pellet was washed in 70% ethanol then air-dried and reconstituted in 25µl sterile water.

Polymerase Chain Reaction (PCR)

PCR was carried out using 2X Biomix Red® (Bioline, London, UK) premix according to the manufacturer's instructions. 10µl of the premix was mixed with 9µl of nuclease free water and 1µl of the DNA at 50ng/µl added. The universal primer pair HCO 2198 5'TAAACTTCAGGGTGCCAAAAAATCA-3' and LCO 1490 5'-GGTCAACAAATCATAAAGATATTGG-3' was used to amplify an approximately 700 base pair

DNA fragment of the mitochondrial gene (Former *et al*., 1994). PCR cycling conditions were initial denaturation 94°C, 3 minutes followed by 30 cycles at 94°C for 30 seconds, an annealing step at 55°C, an extension step at 72°C for 1 minute and a final extension of 72°C degrees for 10 minutes on a thermal cycler (ABI-Applied Biosystems, Veriti, USA).

Purification and sequencing

Successful PCR was confirmed on a 1.5% agarose gel. PCR products were purified by selective adsorption to silica gel membranes under controlled ionic conditions using the MinElute® PCR purification kit (Qiagen, Hilden, UK) according to the manufacturers' instructions. The purified PCR products were quantified using a Nanodrop® spectrophotometer (Thermo Scientific) and diluted to the required concentration specified by the sequencing service provider (Source Biosciences Lifesciences, Nottingham, UK). All the amplicons were sequenced in both the forward and reverse directions using the respective forward and reverse primers used to generate them. Identification was done by checking for homology using BLAST.

3.10.2 Identification of other insect pests and natural enemies

All other insect pests and natural enemies collected in this study were identified using reference specimens at the Insect Museum of the Department of Animal Biology and Conservation Science (DABCS), University of Ghana, Accra. Samples of larvae of diamondback moth, coccinellids and syrphids were cultured in the laboratory to the adult life stage to allow identification by comparison with labelled specimens in the insect museum. Voucher specimen of all the insect species collected were also deposited in this insect museum.

3.11 Data analysis

The data were subjected to ANOVA using repeated measures procedure of SAS (SAS Institute Inc. 2014). Mean separation was done using the Student Newman-Keuls (SNK) test ($P<0.05$) when ANOVA was significant. Number of insects that were collected was square root transformed before analysis. Data on percentages and proportions were arcsine square root transformed before analysis. Back transformed data were however reported in tables and text. Multiple regression was used to test the relationship between climatic factors (temperature, rainfall and relative humidity) and aphid populations. T-test was used to compare insect populations and yield between the minor and the major seasons.

CHAPTER FOUR

4.0 RESULTS

4.1 Identification of aphids on cabbage

4.1.1 Morphological identification

Following morphological identification, the aphid species present on cabbage were *Lipaphis erysimi* (Kaltenbach) (Hemiptera: Aphididae) and *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) (Plate 18A and B). This is the first formal report of the presence of *Lipaphis erysimi* on cabbage in Ghana. The features for morphological identification are given in Table 5 below.

Table 5: Key morphological features for identification of *Lipaphis erysimi* and *Myzus persicae*

Feature	***Lipaphis erysimi***	***Myzus persicae***
Frontal tubercles	Diverging and not distinctly exceeding vertex	Pronounced and converging
Cornicles	Cornicles are not dark and distinctly longer than the cauda;	Cornicles are the same color as the body; and are long, > 2 times the length of the cauda
Waxy secretion	Slightly visible thin layer of white, waxy secretions	No waxy secretion
Cauda	Tongue-shaped	Cone-shaped

Source: Blackman and Eastop, 1985

*Refer to plates 18A and B for distinguishing features

Plate 17: Pictures of *M. persicae* (A) and *L. erysimi* (B) showing distinctive features (magnification: x40) (photo by: Dr. Maxwel Billah)

4.1.2 Molecular identification

Further molecular analysis carried out, also confirmed the morphologically identified species of aphids. DNA barcoding using universal primers (HCO- 2198 & LCO-1490) for the detection of the mitochondria Cytochrome Oxidase subunit I (COI) gene (700bp fragment) and was subsequently sequenced (Plate 18), which is typical of aphids. Following sequencing and homology check using NCBI-BLAST, two species of aphids, the mustard aphid, *Lipaphis erysimi* Kalt, which is the most abundant, and the generalist aphid and *Myzus persicae* (Sulzer) were identified.

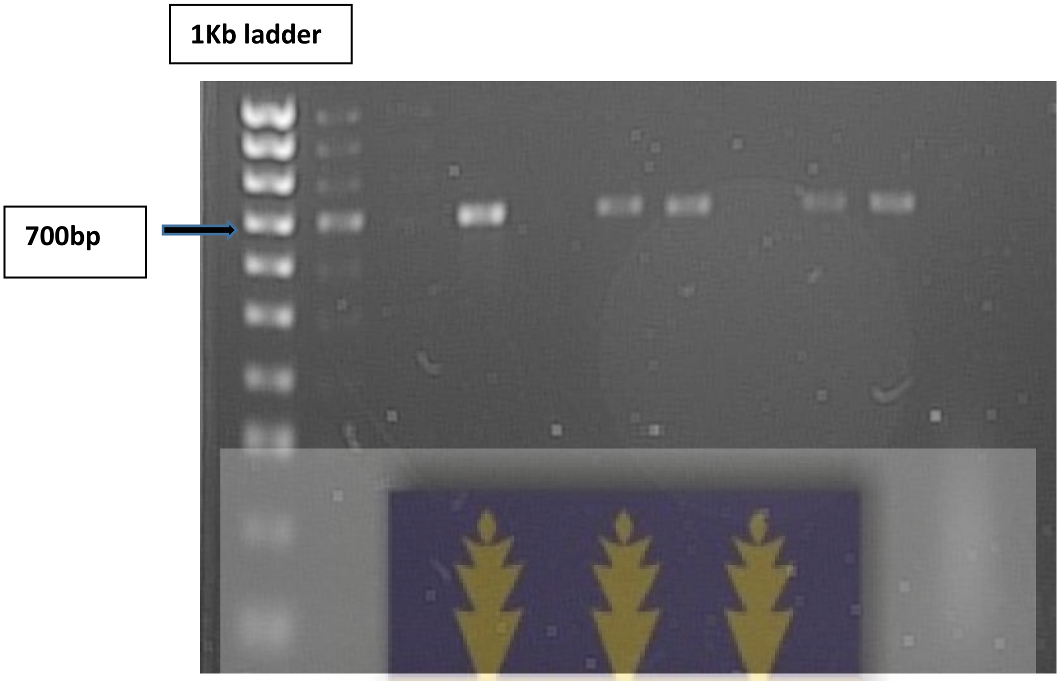


Plate 18: Gel electrophoresis showing 700bp fragment of 5' region of the mitochondria *cytochrome oxidase I* – (*CO-I*) gene for identification of aphid species.

4.2 Effect of treatments on aphids

Generally, neem was very effective in controlling the aphids; *L. erysimi* and *M. persicae* for the two seasons than the synthetic insecticides (Figs. 1-4).

4.2.1 *Lipaphis erysimi*

Lipaphis erysimi infestation started in the first sampling week for the two seasons and increased progressively throughout the sampling period. The population of *L. erysimi* was at its peak in the third and fourth week for the major season and fifth week for the minor season of 2015 (Figs. 1 and 2). Lambda-cyhalothrin-treated plots recorded the highest number of *L. erysimi* for both the major and minor seasons. Infestations in the botanical-treated and chlorpyrifos-treated plots were minimal. Neem however recorded the least number of *L. erysimi* for major and minor seasons. There was a significant difference in the effect of the different treatments on *L. erysimi* for both seasons ($F_{5,125} = 3.69$; $P = 0.0380$, and $F_{5,125} = 5.58$; $P = 0.010$, respectively). There was also a significant difference in the effect of each treatment on the population of *L. erysimi* among the weeks of sampling for both seasons ($F_{6,125} = 21.54$; $P < 0.001$ and $F_{6,125} = 9.82$; $P = < 0.0010$). However, the interaction between the spray formulations and weeks of sampling of *L. erysimi* was not significant for the major season ($F_{30,125} = 1.75$; $P = 0.1340$) but significant for the minor season ($F_{30,125} = 3.03$; $P = 0.008$). A *t* test between *L. erysimi* count for both season, revealed no significant difference (Appendix 1).

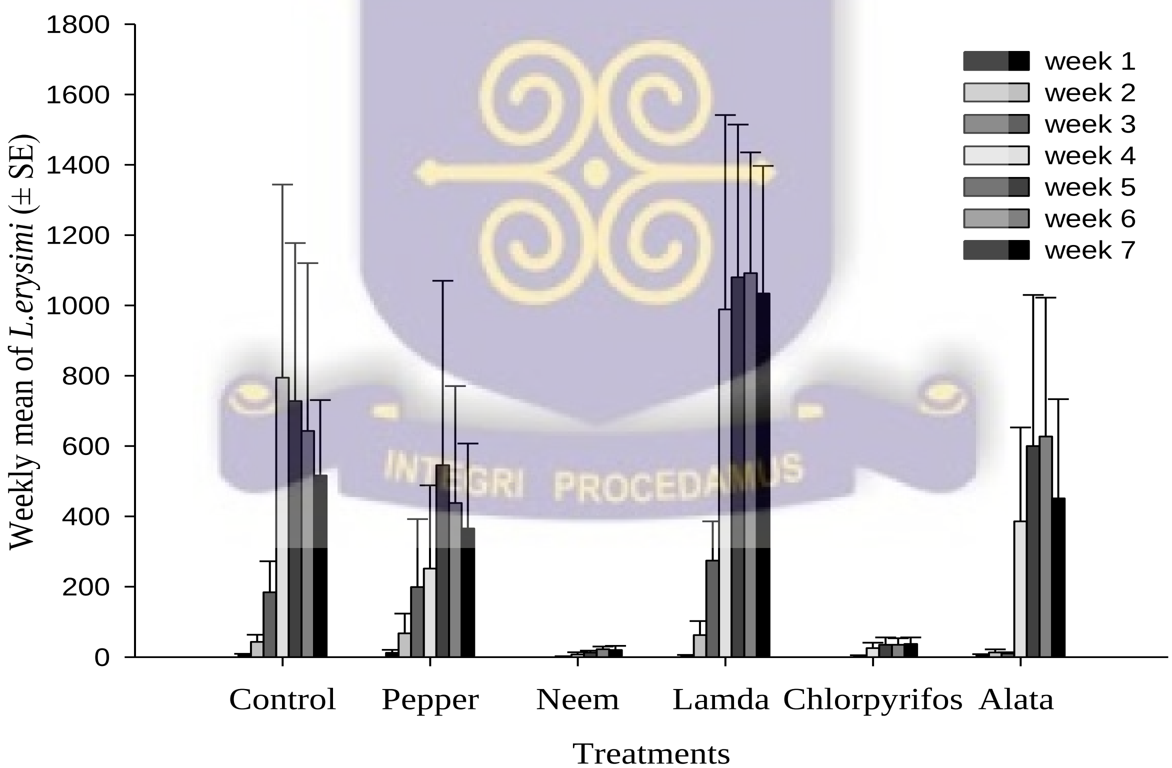


Fig. 1: Effects of treatments on mean (± *SE*) weekly count of *L. erysimi* per cabbage plant during the major season, 2015 in Kpong, Ghana.

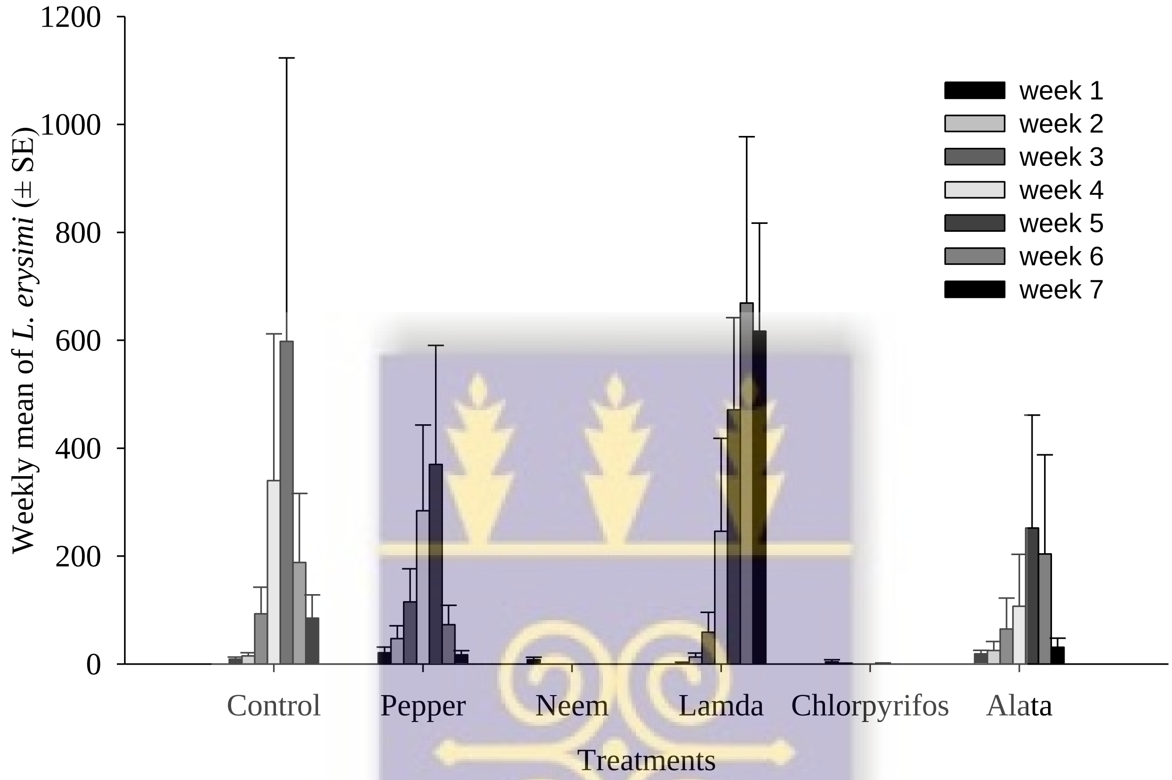


Fig. 2: Effects of treatments on mean (± *SE*) weekly count of *L. erysimi* per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.2.2 *Myzus persicae*

Myzus persicae infestation started in the first week of sampling, depending on the treatment for the major season, and in the fourth week for the minor season and progressively increased throughout the sampling period of 2015 (Figs. 3 and 4). Infestation by this pest was generally low throughout the sampling period for both seasons. Plots sprayed with botanical insecticides and water, had very low infestation for the major season compared to the synthetic insecticides. In the minor season, infestation was minimal in the botanical-treated and chlorpyrifos-treated plots.

Highest *M. persicae* numbers were recorded in the lambda-cyhalothrin-treated plots for the major season and the control plots for the minor season. However, neem-treated plots recorded no *M. persicae* for both seasons. There was no significant difference in the *M. persicae* population among the treatments for both seasons ($F_{5,125} = 1.67$; $P = 0.2290$ and $F_{5,125} = 0.71$; $P = 0.6310$). The effect of treatments on the *M. persicae* population among the sampling weeks was significant for the major season ($F_{6,125} = 12.55$; $P = 0.0030$) but not significant for the minor season ($F_{6, 125} = 2.10$; $P = 0.170$). However, the interaction between the treatments and the sampling time for the *M. persicae* population was not significant for both seasons ($F_{30, 125} = 1.54$; $P = 0.2400$ and $F_{30, 125} = 0.79$; $P = 0.5850$). Comparison between *M. persicae* counts for both seasons showed that there was no significant difference (Appendix 1)

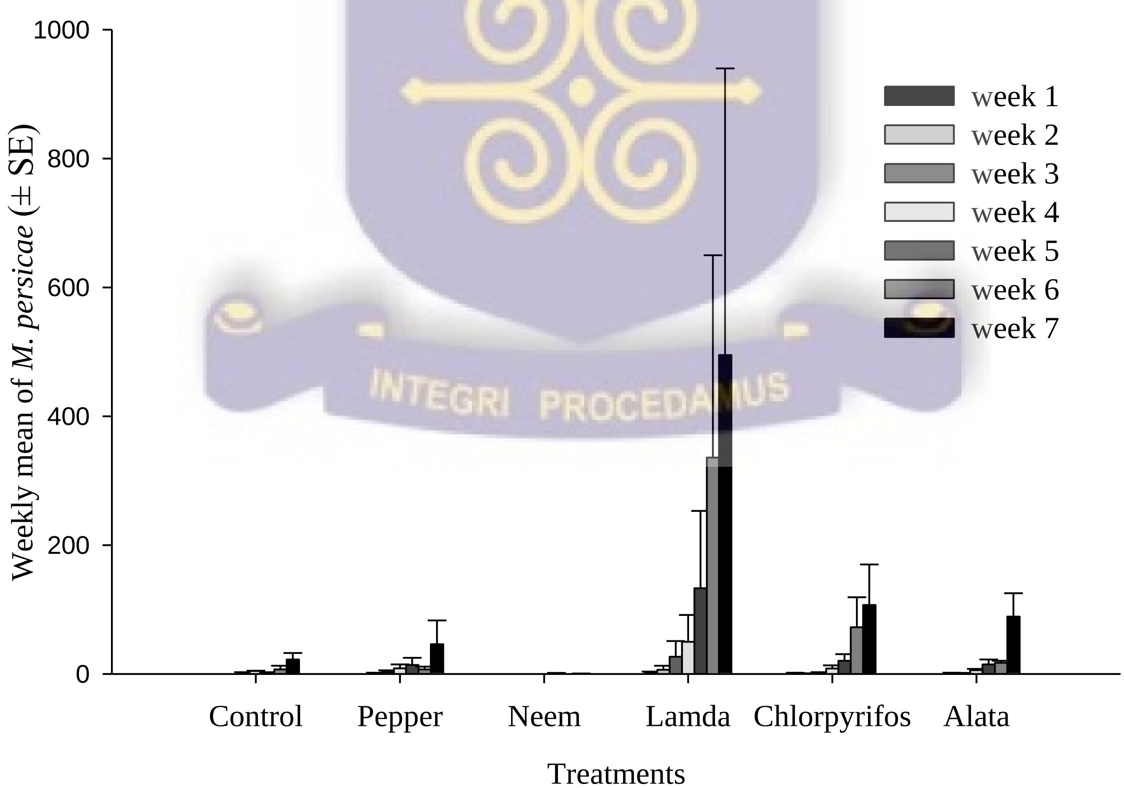


Fig. 3: Effects of treatments on mean (±SE) weekly count of *M. persicae* per cabbage plant during the major season, 2015 in Kpong, Ghana

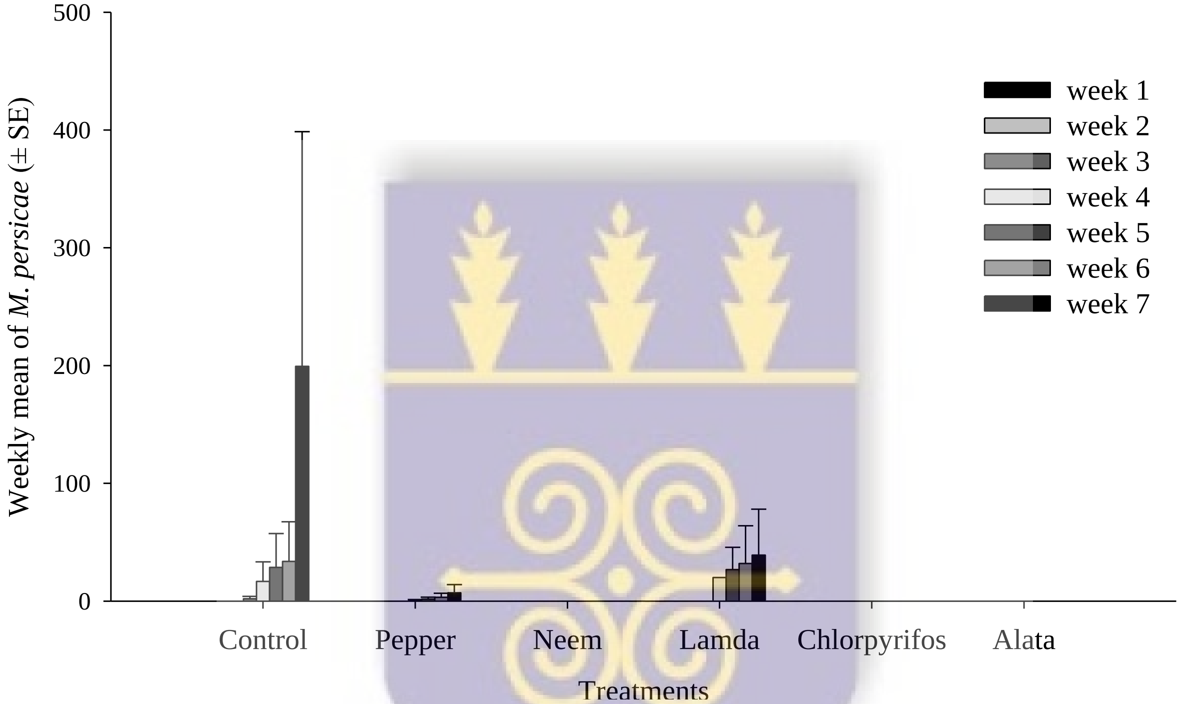


Fig. 4: Effects of treatments on mean (±SE) weekly count of *M. persicae* per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.3 Effect of treatments on natural enemies

4.3.1 *Paragus borbonicus*

The population of hoverfly, *Paragus borbonicus* started at the first week of sampling and progressively increased until it reached its peak population in the fifth week of sampling for the control plots for both seasons (Figs. 5 and 6). Plots sprayed with neem, lambda-cyhalothrin and chlorpyrifos had the least number of hoverflies for both seasons. Control plots recorded the highest number of hoverflies, followed by the pepper and *alata samina*-treated plots. The number of hoverflies were significantly different among the treatments for both seasons ($F_{5,125} = 5.23$; $P = 0.0130$ and $F_{5, 125} = 4.17$; $P = 0.0260$). There was also a significant difference in the effect of treatments on the hoverfly population among the weeks of sampling for the major season ($F_{6,125} = 13.00$; $P < 0.0010$) and no significant difference during the minor season ($F_{6,125} = 2.63$; $P = 0.0920$). The interaction between the treatments and sampling time was significant for the major season ($F_{30,125} = 2.30$; $P = 0.0260$) and not significant for the minor season ($F_{30,125} = 1.82$; $P = 0.1090$). There was also no significant difference between the major and minor season counts of *P. borbonicus* (Appendix 1)

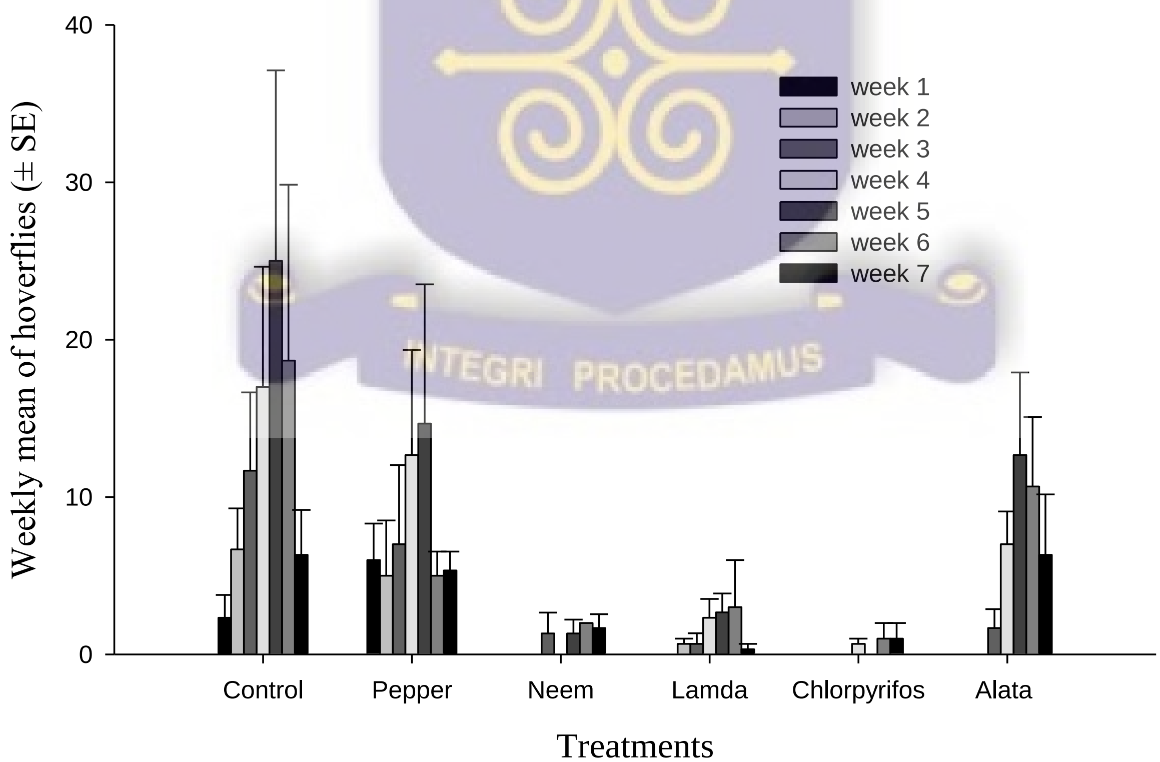


Fig. 5: Effects of treatments on mean (± *SE*) weekly count of the hoverfly, *P. borbonicus*, per cabbage plant during the major season, 2015 in Kpong, Ghana.

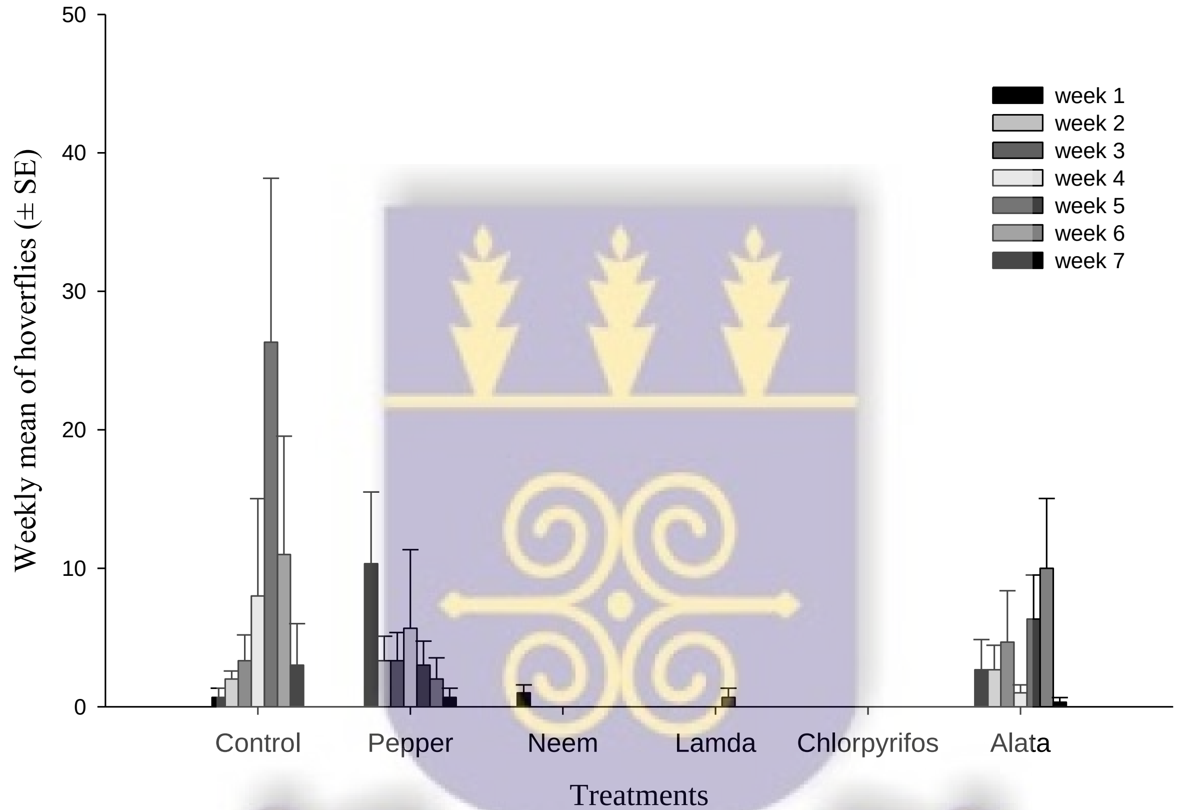


Fig. 6: Effects of treatments on mean (± *SE*) weekly count of the hoverfly, *P. borbonicus*, per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.3.2 Ladybird beetle, *Cheilomenes* spp.

The ladybird, *Cheilomenes* spp. population started building up from the first week of sampling and reached its peak in the fourth and fifth week of sampling for the major and minor seasons of 2015, respectively (Figs. 7 and 8). Control plots, pepper-treated plots and *alata samina*-treated plots recorded the highest number of ladybirds for both seasons. The neem, lamda-cyhalothrin and chlorpyrifos treated plots recorded the least number of ladybirds for both seasons. There was significant difference in the ladybird abundance among the treatments for the major season ($F_{5,125}$ = 3.92; P = 0.0310), but no significant difference for the minor season ($F_{5,125}$ = 1.82; P = 0.1960). There was also a significant difference in the effect of each treatment on the ladybird population among the weeks of sampling for the major season ($F_{6,125}$ = 12.87; P < 0.0010) and no significant difference for the minor season ($F_{6,125}$ = 1.47; P = 0.2520). The interaction between the treatments and sampling time was not significant for both seasons ($F_{30,125}$ = 1.69; P = 0.1530 and $F_{30,125}$ = 0.69; P = 0.7060). Comparison between *Cheilomenes* spp. counts for both seasons showed a significant difference (appendix 1).

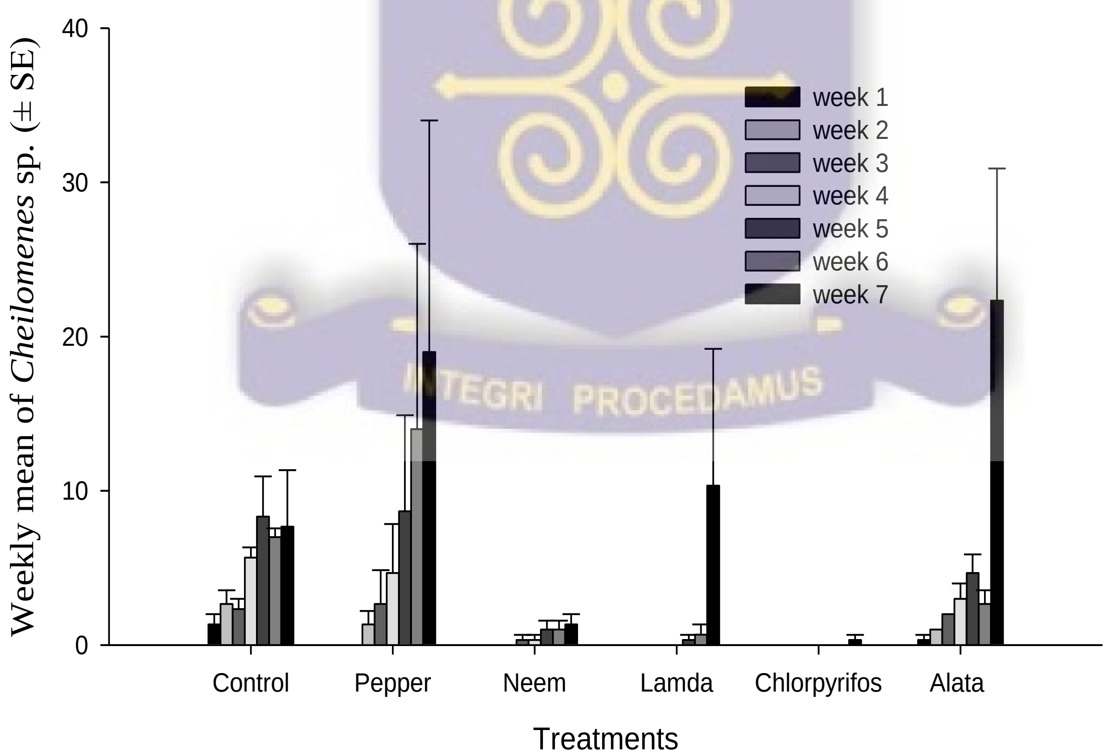


Fig. 7: Effects of treatments on mean (± *SE*) weekly count of the ladybird beetle, *Cheilomenes* spp., per cabbage plant during the major season, 2015 in Kpong, Ghana.

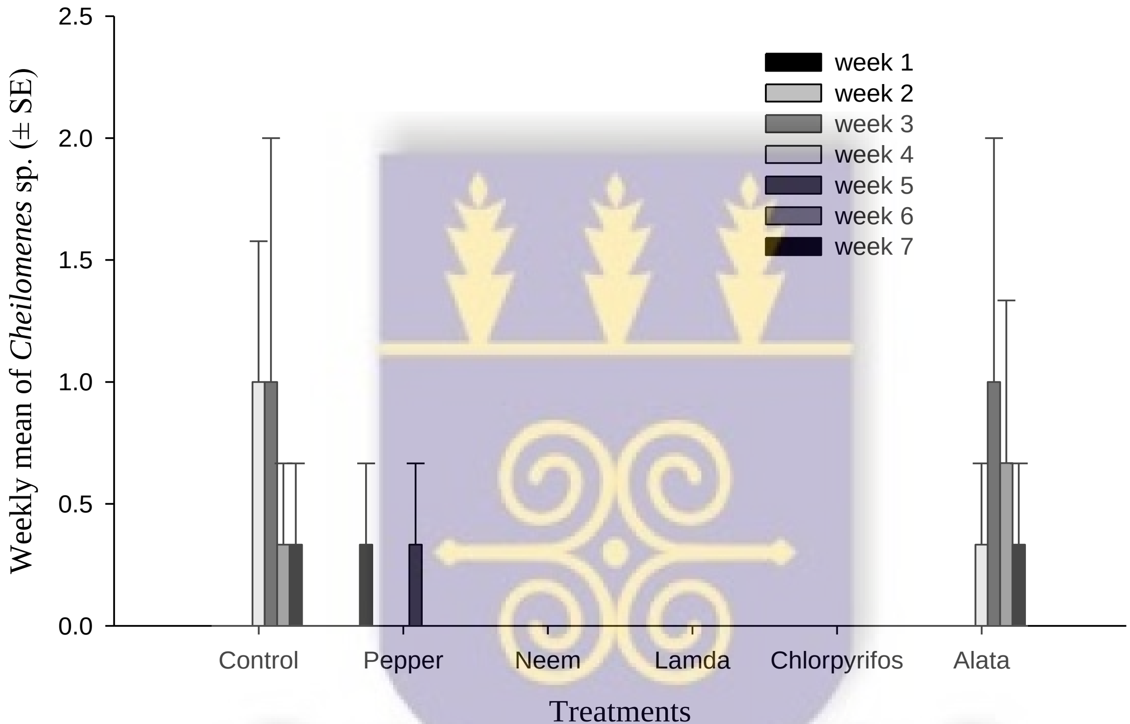


Fig. 8: Effects of treatments on mean (± *SE*) weekly count of the ladybird beetle, *Cheilomenes* spp. per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.3.3 Spiders

The number of spiders started to build up in the first week of sampling and continued increasing until its peak at the fifth week of sampling for both seasons (Figs. 9 and 10). Control plots recorded the highest number of spiders followed by the botanical-treated plots for both seasons. Plots sprayed with synthetic insecticides recorded the lowest number of spiders for both seasons. There was a significant difference among the different treatments in controlling the spiders for both seasons ($F_{5,125} = 21.27$; $P < 0.0010$ and $F_{5,125} = 61.95$; $P < 0.0010$). The effect of each treatment on the spider population among the sampling weeks for both seasons were also significantly different ($F_{6,125} = 12.30$; $P < 0.0010$ and $F_{6,125} = 55.91$; $P < 0.0010$). However, the interaction between the sampling weeks and treatments was not significant for the major season ($F_{30,125} = 1.68$; $P = 0.0670$), but significant for the minor season ($F_{30,125} = 4.40$; $P = 0.0010$). A *t*-test showed that there were no differences in the spider count for the major and minor season (appendix 1).

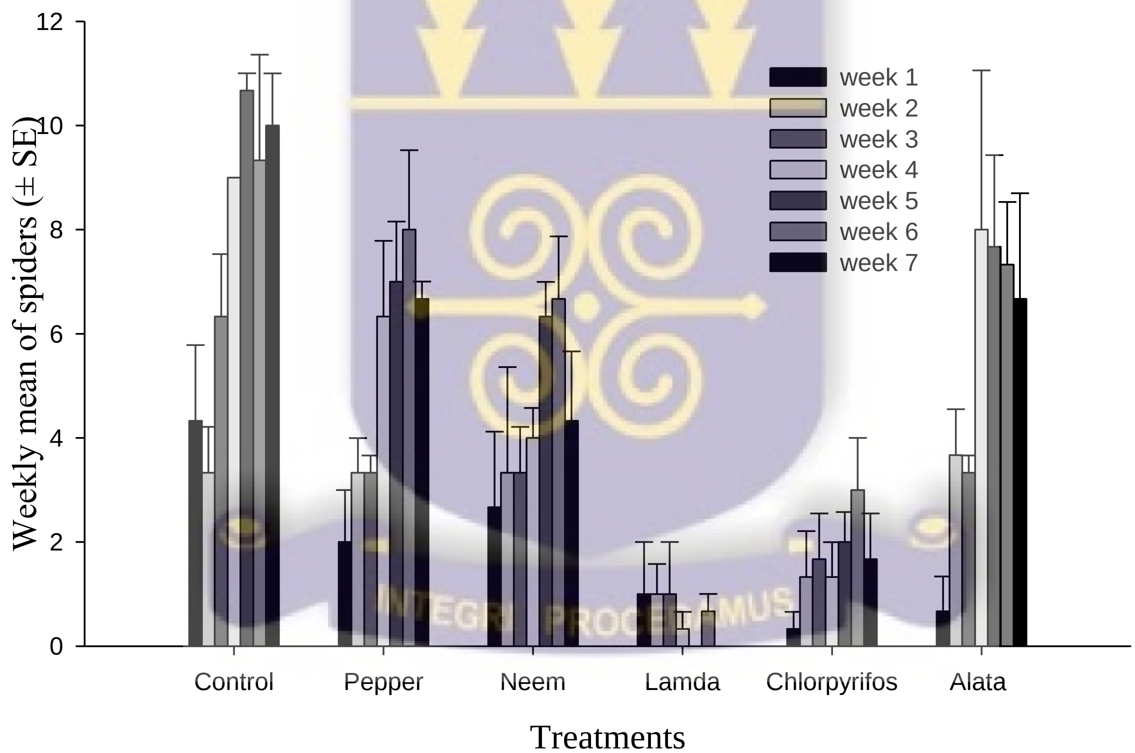


Fig. 9: Effects of treatments on mean (± *SE*) weekly count of the spiders (Araneae) per cabbage plant during the minor season, 2015 in Kpong, Ghana.

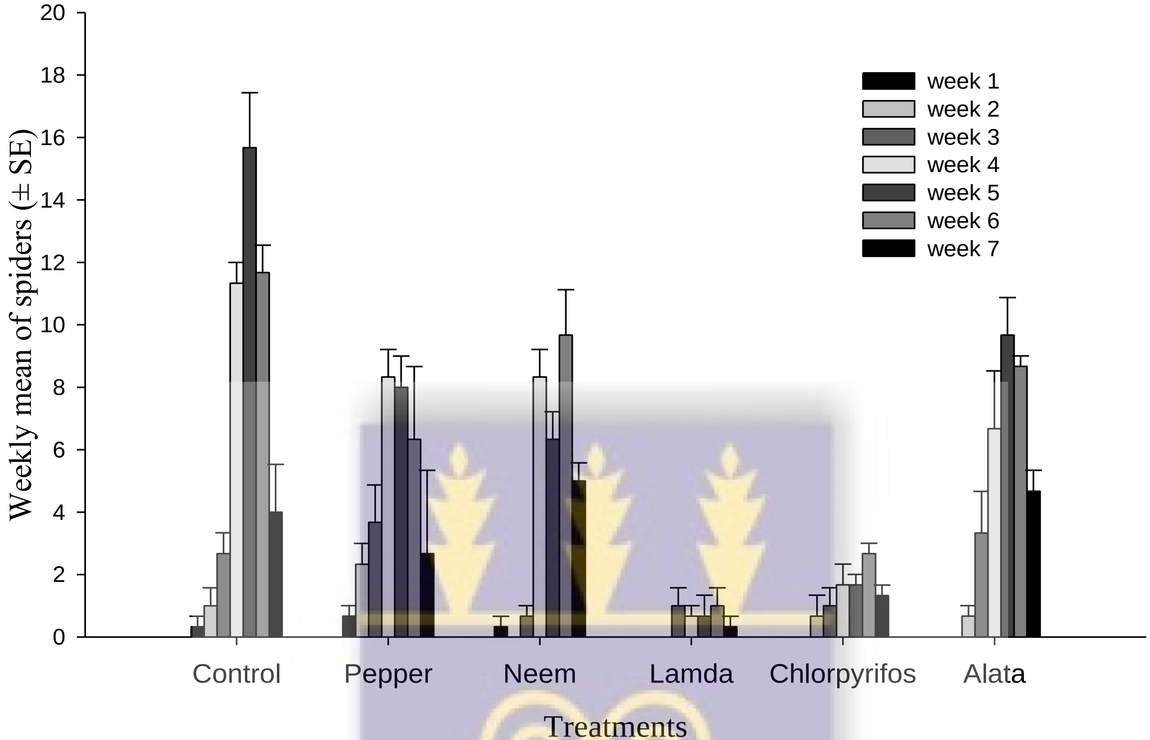


Fig. 10: Effects of treatments on mean (± *SE*) weekly count of the spiders (Araneae) per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.3.4 *Diaeretiella rapae*

Populations of the cabbage aphid parasitoid, *D. rapae* were very low throughout the sampling period for the major season. All treatments except control and pepper-treated plots recorded no *D. rapae* for the entire season. The treatments showed no significant difference for *D. rapae* populations ($F_{5,\ 125} = 1.82$, $P = 0.1960$). The effect of the treatments on the weekly sampling of *D. rapae* was not significant for the major season ($F_{6,\ 125} = 1.70$, $P = 0.2070$). The interaction between the sampling weeks and treatments on *D. rapae* numbers was also not significant ($F_{30,\ 125} = 1.26$, $P = 0.3140$). *Diaeretiella rapae* was absent in the minor season. A *t*-test showed that there were no significant differences in *D. rapae* counts for the major and minor seasons (appendix 1).

4.4 Percentage parasitism by *D. rapae*

Throughout the sampling period, *D. rapae* and 'mummies' were observed only in the major season, in pepper and control plots. A total of 12 and 8 mummies were recorded in the control and pepper plots, respectively of which, two mummies and one parasitoid was recorded in the control and pepper plots after rearing aphids for parasitoids, respectively. The percentage parasitism for the aphids in the control plots was 0.009% and 0.019% for the pepper after calculation according to Mussury and Fernandes, 2002 procedure.

4.5 Percentage of alates

Although there was no significant difference in the percentage of alate between the treatments for the major season, the highest percentage was recorded in the neem-treated plots followed by the alata samina-treated plots for the major season (Table 6). Whereas in the minor season, there was a significant difference in the percentage of alate between the treatments. Alata samina-treated plots recorded the highest percentage of alate, followed by the lambda cyhalothrin-treated plots (Table 6).

Table 6: Percentage alate per cabbage plant for the major and minor seasons

Treatment	**Percentage Alate**	
	Major season	**Minor season**
Control	3.04±2.535b	1.68±1.603b
Pepper	1.69±0.311b	1.10±0.613b
Neem	6.77±2.815a	0.00±0.00b
Lambda-Cyhalothrin	1.91±1.426b	2.99±2.150bc
Alata Samina	3.38±1.946b	7.70±2.641ac
Chlorpyrifos	1.5±0.889b	0.00±0.00b
F	1.18	3.65
P	0.386	0.039

4.6 Effect of treatments on the abundance of other insect pests.

Other insect pests encountered apart from aphids during sampling for the major season include: *Plutella xylostella* (Diamondback moth), *Hellula undalis* (cabbage webworm), *Spodoptera* sp., grasshoppers and whiteflies, *Bemisia tabaci*. *Spodoptera* sp. and grasshoppers were only spotted once on the field. The other insect pest persisted throughout the sampling period.

4.6.1 *Plutella xylostella* (Diamondback moth)

Plutella xylostella infestation started in the first week of sampling and increased steadily until the last week where it reached its peak for the major and minor seasons (Figs. 11 and 12). Control and the synthetic chemical-treated plots recorded the highest number of DBM for the major season, while for the minor season, lambda and chlorpyrifos-treated plots recorded the highest number of *P. xylostella* larvae. Neem-treated plot however, recorded the least number of DBM for both seasons, followed by alata samina and pepper-treated plots. There was a significant difference among the different treatments in controlling DBM for both seasons ($F_{5,125} = 30.49$; $P < 0.0010$ and $F_{5,125} = 99.82$; $P < 0.0010$). The effect of each treatment on DBM population among the weeks of sampling for both seasons were also significantly different ($F_{6,125} = 83.45$; $P < 0.0010$ and $F_{6,125} = 85.23$; $P < 0.0010$). The interaction between the sampling weeks and treatment was also significant for the major and minor seasons ($F_{30,125} = 3.95$; $P = 0.0070$ and $F_{30,125} = 29.41$; $P < 0.0010$). A *t* test showed that there was no significant difference in DBM counts for the major and minor seasons (appendix 1).

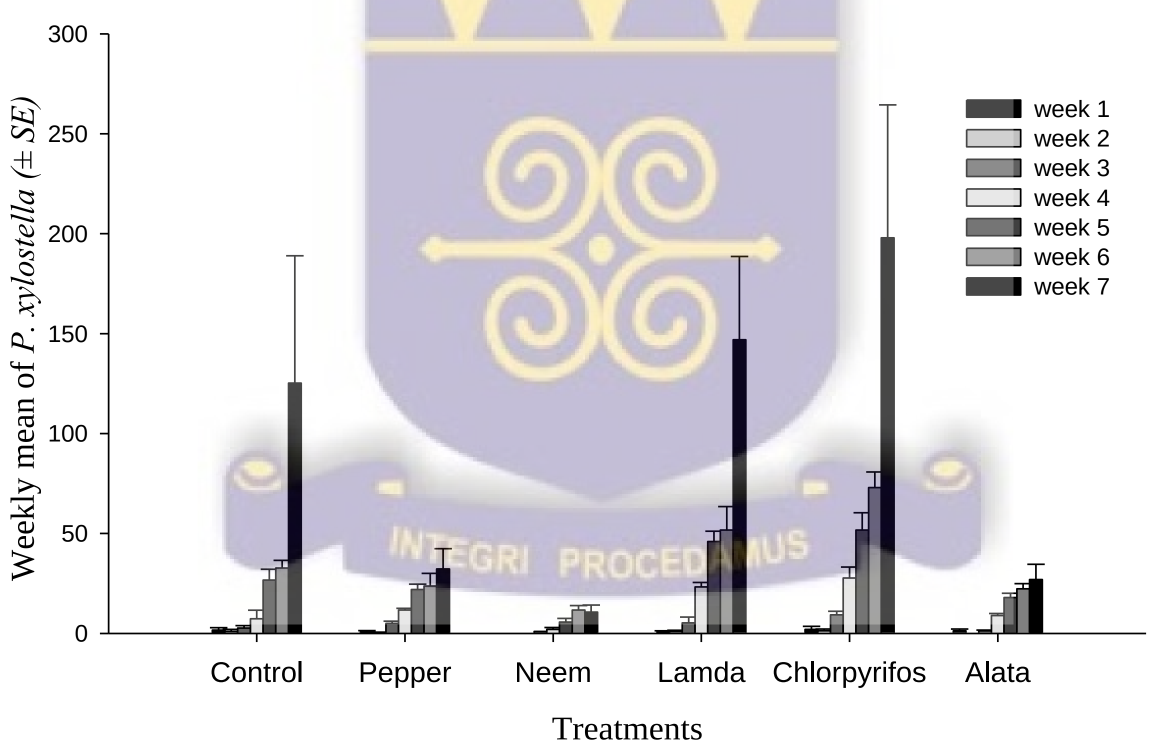


Fig 11: Effects of treatments on mean (± *SE*) weekly count of DBM per cabbage plant during the major season, 2015 in Kpong, Ghana.

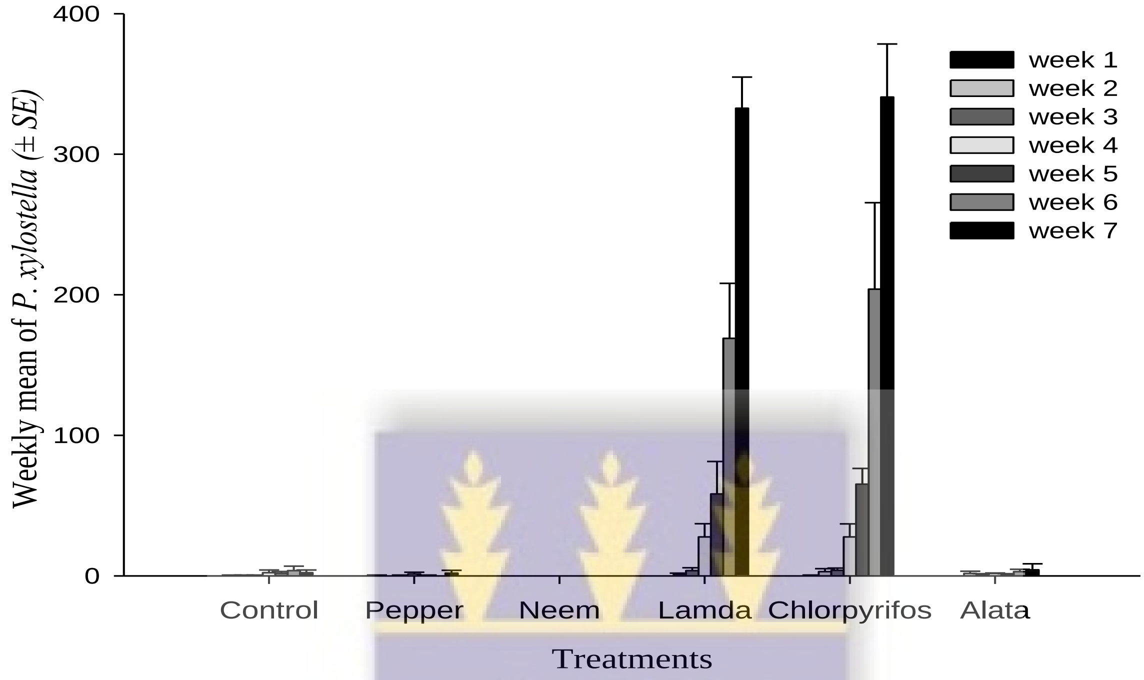


Fig 12: Effects of treatments on mean (± *SE*) weekly count of DBM per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.6.2 *Hellula undalis*

The population of *H. undalis* was low throughout the sampling period for both seasons. Many treatment plots did not record any *H. undalis* for the whole sampling period. Peaks were observed in the second and fifth week in the major season and fourth week in the minor season for the control plot (Fig. 13 and 14). There was a significant difference among the different treatments in controlling *H. undalis* for both seasons ($F_{5,125} = 5.86$; $P = 0.0090$ and $F_{5,125} = 39.43$; $P < 0.0010$). The effect of each treatment on H. undalis population among the weeks of sampling was not significantly different for the major season ($F_{6,125} = 1.22$; $P = 0.314$) but significantly different for the minor season ($F_{6,125} = 6.90$; $P = 0.0010$). However, the interaction between the sampling weeks and treatment was not significant for the major and minor seasons ($F_{30,125} = 0.99$; $P = 0.476$ and $F_{30,125} = 1.98$; $P = 0.053$). A *t*-test showed that there was no significant difference in *H. undalis* counts for the major and minor seasons (appendix 1).

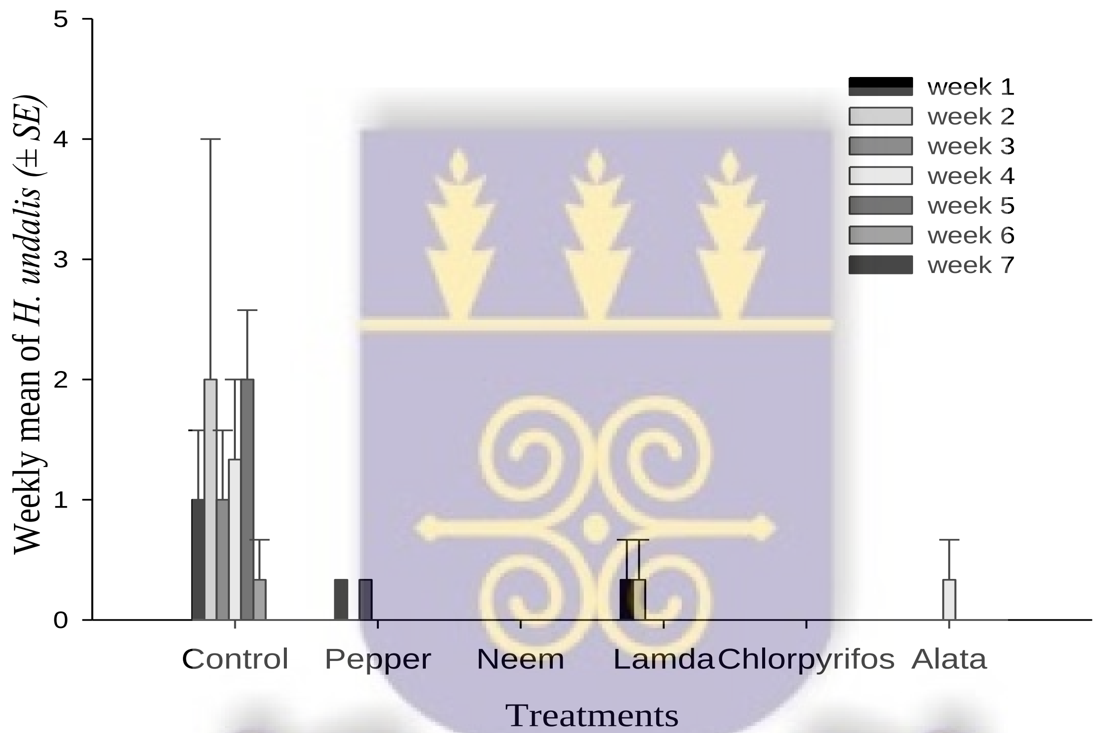


Fig 13: Effects of treatments on mean (± *SE*) weekly count of H. undalis per cabbage plant during the major season, 2015 in Kpong, Ghana.

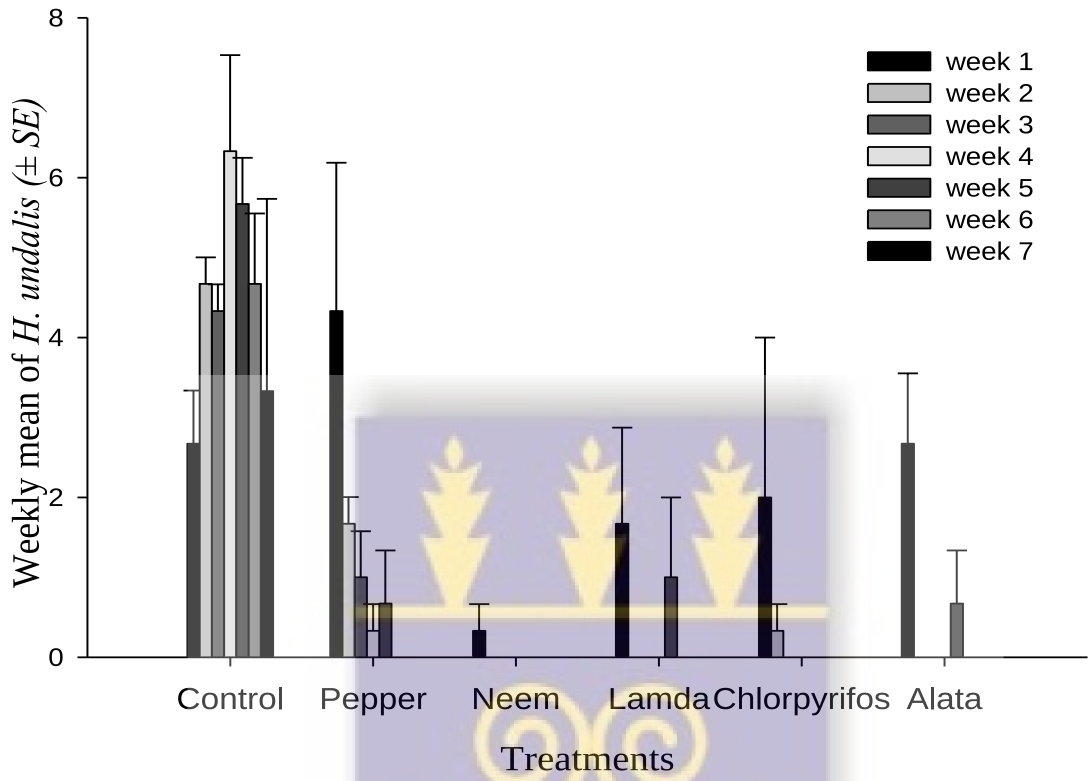


Fig 14: Effects of treatments on mean (± *SE*) weekly count of H. undalis per cabbage plant during the minor season, 2015 in Kpong, Ghana.

4.6.3 *Bemisia tabaci*

Bemisia tabaci infestation started from the first week of the sampling period and progressed until it reached its peak during the third and fourth weeks for the major and minor seasons, respectively (Fig. 15 and 16). Whitefly population was highest in the minor than the major season, and least numbers were recorded in the neem-treated plot for the two seasons. There was a significant difference among the different treatments in controlling whiteflies for both seasons ($F_{5,125} = 25.71$; $P < 0.0010$ and $F_{5,125} = 4.74$; $P < 0.0180$). The effect of each treatment on whitefly population among the weeks of sampling for both seasons were also significantly different ($F_{6,125} = 47.89$; P

< 0.0010 and $F_{6,125}$ = 384.22; P < 0.0010). The interaction between the sampling weeks and treatment was also significant for the major and minor seasons ($F_{30,125}$ =4.92; P < 0.0010 and $F_{30,125}$ = 2.80; P = 0.0110). A *t*-test showed that there was a significant difference in *B. tabaci* counts for the major and minor seasons (appendix 1).

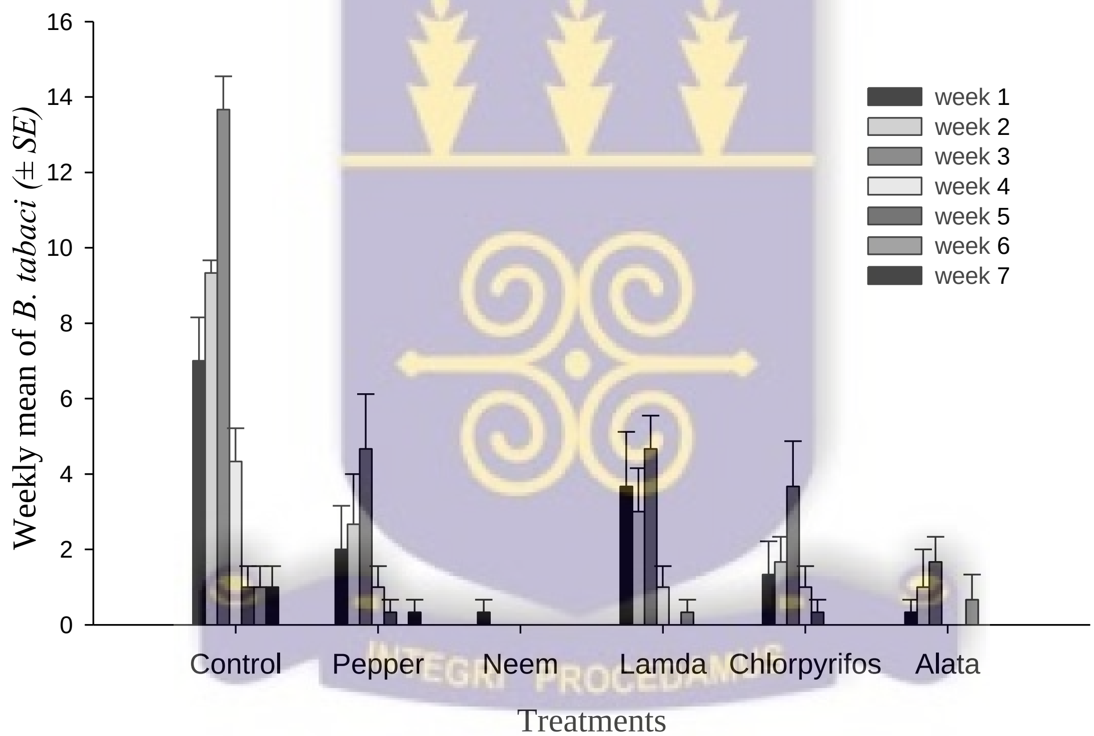


Fig 15: Effects of treatments on mean (± *SE*) weekly count of B. tabaci per cabbage plant during the major season, 2015 in Kpong, Ghana.

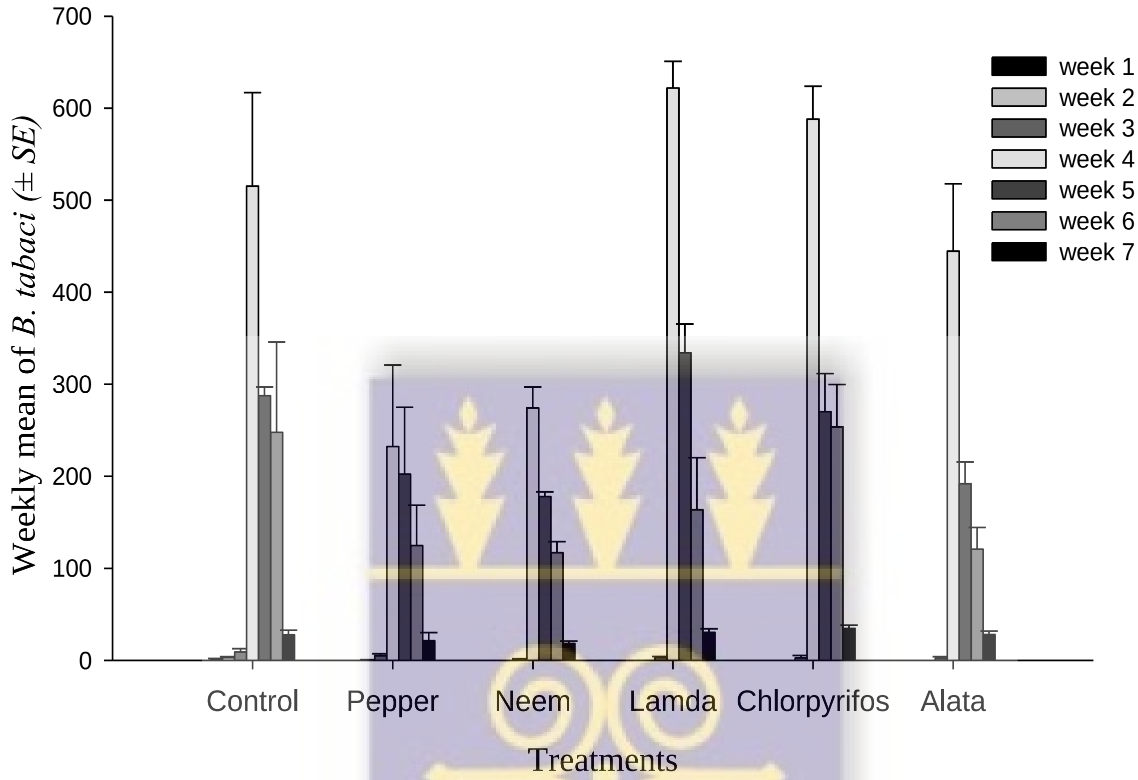


Fig 16: Effects of treatments on mean (± *SE*) weekly count of B. tabaci per cabbage plant during the major season, 2015 in Kpong, Ghana.

4.6.4 Other insect pest of cabbage found during the sampling period

Hellula undalis larva

Plutella xylostella adult

Estigmene sp. larva

Grasshopper

Spodoptera sp. larva

Bemisia tabaci adult

Plate 19: Other insect pest found on cabbage

4.7 Yield assessment

The mean yield among the treatments was significantly different for the major and minor seasons of 2015. The neem treated plots had significantly higher yields than lambda-cyhalothrin treated plots, but it was not significantly different from the rest of the treatments during the major season (Table 7). However, during the minor season, the highest yield was obtained in the neem sprayed plots. A *t* test revealed that there were significant differences in the yield for the major and minor season for control, pepper and neem plots (Table 7).

Table 7: Mean (± *SE*) yield of cabbage under different treatments during the major and minor seasons of 2015, Kpong, Ghana.

Treatment	Mean yield (tonnes/hectare)		*t*-value	*P*
	Major season	Minor season		
Control	12.37 ±1.27ab	0.593±0.0664c	8.94	0.012
Pepper	12.37 ± 1.30ab	6.503±0.7364c	3.93	0.017
Neem	17.80 ± 2.61a	28.36±0.971a	4.08	0.015
Lambda-cyhalothrin	6.03 ±2.08b	5.067±2.809c	0.27	0.797
Alata samina	14.57 ± 2.75ab	15.05±3.052b	0.12	0.912
Chlorpyrifos	13.40 ±1.99ab	10.02±3.702bc	0.8	0.466
F	3.47	22.14		
P	0.0359	< 0.001		

Means with the same letter(s) are not significantly different (P < 0.05, SNK test) within columns. Means between seasons for each treatment was compared using *t* test (P < 0.05).

4.8 Damage assessment and yield quality

Damage on cabbage plants included multiple heads, ‘suspected’ viral disease incidence and severity, and number of holes on cabbage heads. The intensity of damage on the cabbage heads in the context of number of holes led to classification of head quality into marketable and unmarketable heads. Damage on cabbage heads was highest in the chemical treated plots and control with the highest damage category of 5. Cabbage heads from botanically treated plots fell into the damage 0-2 categories. Within the different treatments, neem recorded the highest number of marketable heads for both seasons (Figs. 17 and 18). Lambda cyahalothrin, however did not record any marketable head for the major season. For the minor season, chlorpyrifos and lambda-cyhalothrin did not record any marketable head.

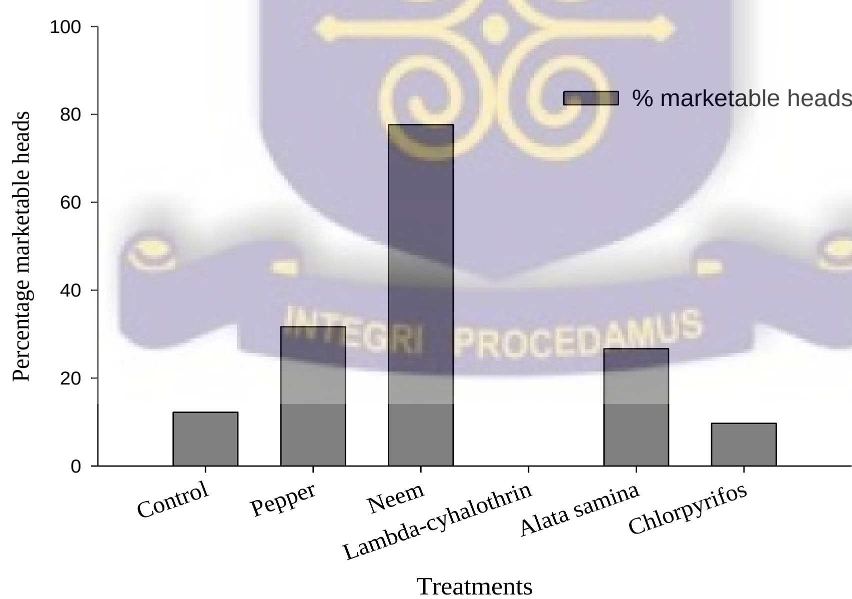


Fig. 17: Mean percentage marketable heads for different treatments during the major season of 2015, Kpong, Ghana.

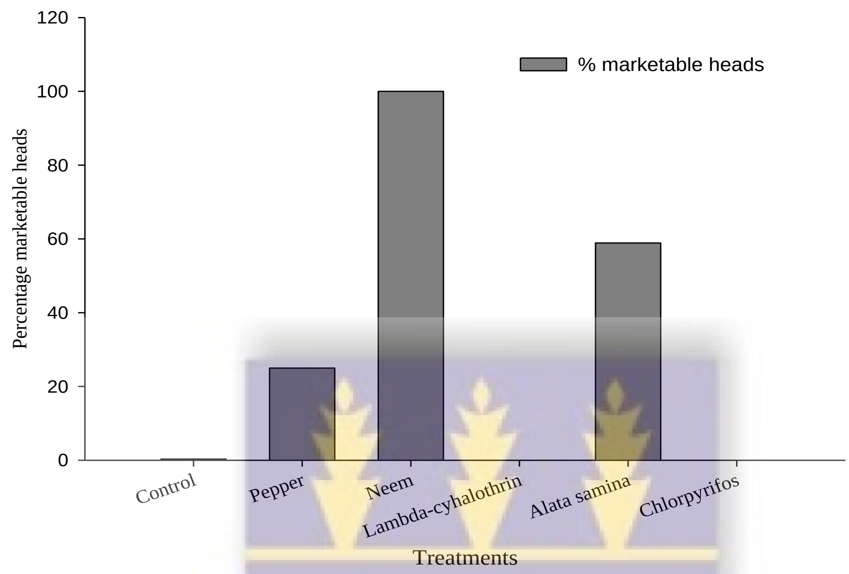


Fig. 18: Mean percentage marketable heads for different treatments during the minor season of 2015, Kpong, Ghana.

Damage due to multiple heads was not significant for the different treatments for both the major and minor seasons. The control plots recorded the highest number of multiple heads for both seasons followed by pepper and chlorpyrifos-treated plots. Neem-treated plots recorded the least number of multiple heads followed by alata samina-treated plots (Table 8)

Though the infestation level (incidence) of the suspected aphid disease was not significant for the different treatments for the major and minor seasons, highest infestation rates were observed in the pepper-treated plots for both seasons, followed by control in the major season and alata samina-treated plots in the minor season (Table 8). However, there was no disease infestation in the neem and chlorpyrifos-treated plots for both seasons.

The severity of the suspected aphid disease among the different treatments was not significant for the major season but significant for the minor season. High disease severity was observed in the control plot for the major season, followed by lambda-cyhalothrin and pepper-treated plots. While plots sprayed with pepper recorded the highest disease severity for the minor season, followed by control (Table 8).

Table 8: Mean (±SE) number of multiple heads, aphid disease severity and percentage disease infestation of cabbage under different treatments during the major and minor seasons of 2015, Kpong, Ghana

Treatments	**Major Season**			**Minor Season**		
	%MHC	**% INCID**	**DI SEV**	**MHC**	**% INCID**	**DI SEV**
Control	1.67±0.882a	11.1±2.940a	2.67±0.667a	52.2±6.759a	43.3±28.360a	2.67±1.202a
Pepper	1±1a	22.2±16.02a	2.33±1.333a	36.7±8.819be	66.7±33.333a	3.33±1.667a
Neem	0±0a	0±0a	0±0a	4.4±1.111c	0±0b	0±0b
Lambda-cyhalothrin	2±0.577a	16±5.364a	2.33±0.882a	21.1±5.556d	24.4±13.650a	1.67±0.882a
Alata samina	0.67±0.667a	7.8±6.961a	1.33±1.333a	14.4±2.940dc	53.3±26.740a	2.33±1.202a
Chlorpyrifos	0.33±0.333a	0.2±0.167a	0.67±0.333a	27.8±4.006de	0±0b	0±0b
F	1.13	2.13	2.72	22.49	2.79	4.16
P	0.4070	0.1450	0.0840	<.0010	0.0780	0.0260

%MHC= percentage multiple head count, DI SEV= disease severity, % INFES= percentage disease incidence

4.9 Effect of climatic factors on the population dynamics of of *L. erysimi* and *M. persicae*

The results on the changing population of the aphids on cabbage due to climatic factors in the major and minor season of 2015 are represented in the Figs 19 and 20 below. It was revealed that peak populations of *L. erysimi* was recorded in the fifth week when the temperature, rainfall and % RH were 31ºC, 0mm, 26.43% and 34.2ºC, 4.9mm, 46% for the major and minor seasons, respectively. While peak population for *M. persicae* was recorded in the seventh week when the temperature, rainfall and % RH were 31.24ºC, 2.79mm, 48.0% and 34.7ºC, 0.957mm, 25.14% for the major and minor seasons, respectively.

Simple correlation between the weather factors and population of aphids on cabbage showed that there was a significant correlation for the two seasons. All the parameters (temperature, rainfall and %RH) were negatively correlated with the population for the major and minor season except temperature which was positively correlated with the population for both seasons. Table 9 shows the correlation coefficient values for each weather factor versus cabbage aphids' population for the major and minor seasons, 2015. Multiple linear regression to determine the role of weather factors on the population changes of aphids of cabbage revealed that there was no combined significant effect of the weather factors on the aphid populations for the major (P = 0.333 for *L. erysimi* and P = 0.785 for *M. persicae*) and minor seasons (P = 0.540 for *L. erysimi* and P = 0.061 for *M. persicae*). However, the effect of %RH on the population of *M. persicae* was significant for the minor season (t = -3.24; P = 0.0480) (Table 10).

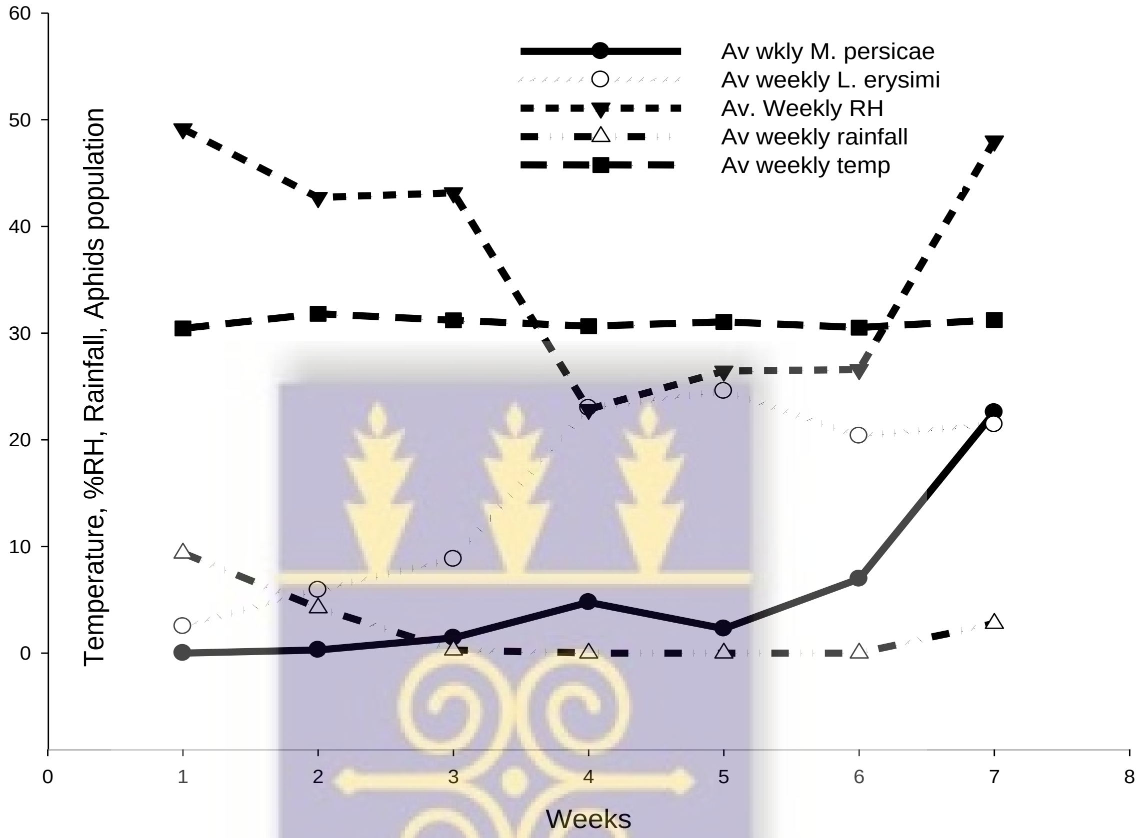


Fig 19: Graphical representation of the impact of weather factors on population fluctuation of aphids on cabbage during the 2015 major season in Kpong, Ghana.

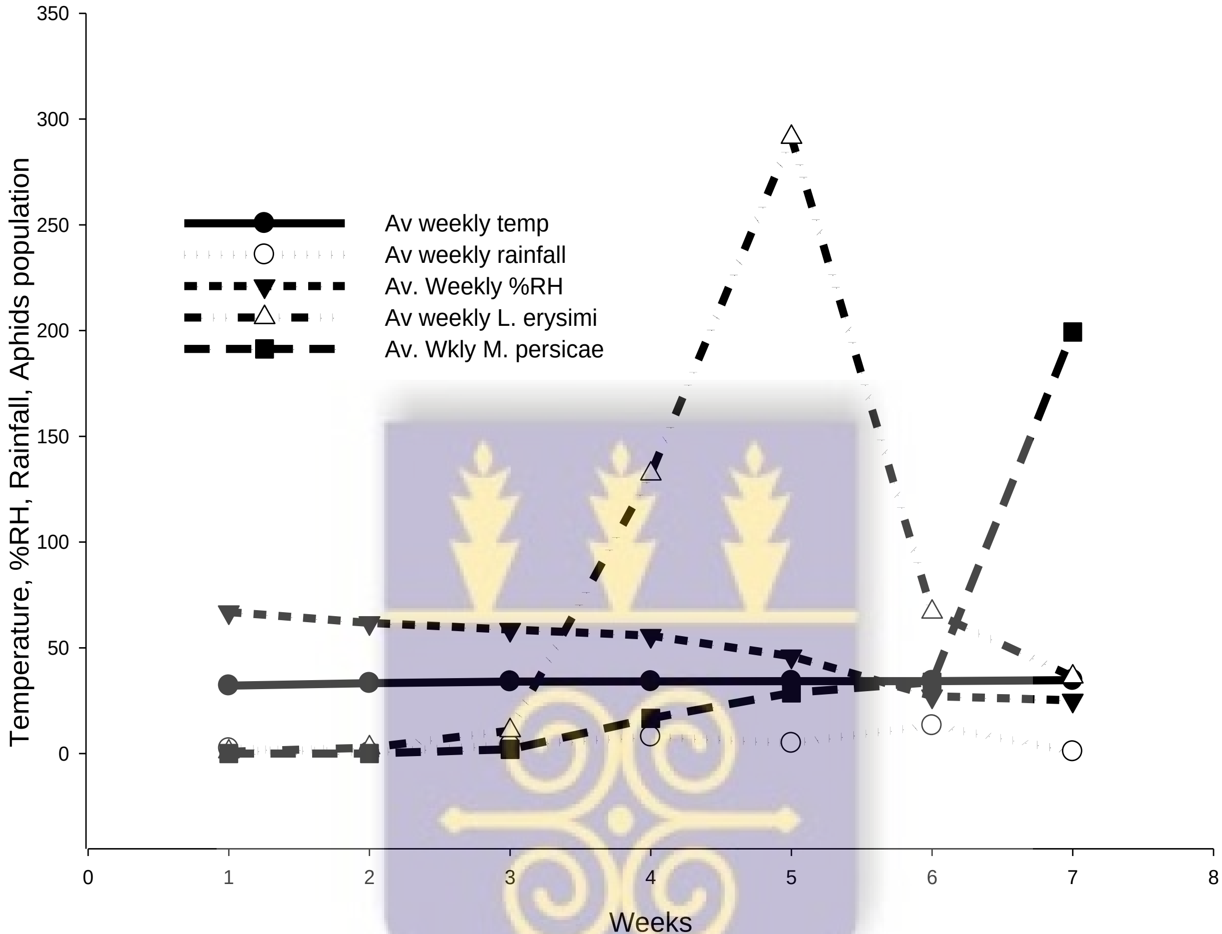


Fig 20: Graphical representation of the impact of weather factors on population fluctuation of aphids on cabbage during the 2015 minor season in Kpong, Ghana.

Table 9: Correlation between weather factors and aphids population, 2015

Seasons	Weather factors	Aphids (r)
Major season	Av weekly temp	-0.996
	Av weekly rainfall	-0.470
	Av. Weekly %RH	0.530
Minor Season	Av weekly temp	-0.998
	Av weekly rainfall	-0.031
	Av Weekly %RH	-0.757

Av=average, %RH=percentage relative humidity

Table 10: Multiple linear regression models between population of aphids on cabbage and weather factors during the major and minor season, 2015.

			……….Regression parameter………..			
Seasons	**Aphids**	**Model**	**B**	**SE**	***t* value**	**r^2**
Major season	*L. erysimi*	Constant	109	240	0.46	75.5%
		Av. Weekly temp	-2.68	8.03	-0.33	
		Av. Weekly rainfall	-1.50	1.52	-0.99	
		Av. Weekly %RH	-0.204	0.502	-0.41	
	M. persicae	Constant	131	296	0.44	
		Av. Weekly temp	-4.62	9.90	-0.47	
		Av. Weekly rainfall	-1.80	1.87	-0.96	
		Av. Weekly %RH	0.598	0.619	0.97	
Minor season	*L. erysimi*	Constant	-2445	3340	-0.73	77.8%
		Av. Weekly temp	70.7	93.5	0.76	
		Av. Weekly rainfall	5.8	12.8	0.45	
		Av. Weekly %RH	2.13	4.98	0.43	
	M. persicae	Constant	211	866	0.24	
		Av. Weekly temp	2.4	24.2	0.10	
		Av. Weekly rainfall	-9.91	3.33	-2.97	
		Av. Weekly %RH	-4.18	1.29	-3.24*	

* =significant difference

CHAPTER FIVE

5.0 DISCUSSION

5.1 Aphid identfication

The main aphids identified during the study were *Lipaphis erysimi* and *Myzus persicae* which have been observed to occur on crucifers in many parts of the world including China, South Africa, Kenya, Benin and Mali (Daiber, 1971; Liu et al., 1997; James *et al*., 2010; Sæthre *et al*., 2011). *Myzus persicae* is a polyphagus aphid with worldwide distribution (CIE, 1979), while *L. erysimi* on the other hand is known to be a specialist aphid on cruciferous crops worldwide (Yue and Liu, 2000). This study reports its presence in Ghana for the first time. This aphid has been shown to transmit about 13 important viruses of brassica (Kennedy *et al.*, 1962), thus its presence in Ghana is of major concern for the cabbage production sector. This aphid could also be the transmitter of the 'suspected' viral disease seen on cabbage during the study period, though there is no evidence to support this hypothesis.

5.2 Effect of treatments on aphids and natural enemies

This study showed that neem is very effective in controlling *L. erysimi* and *M. persicae* on cabbage while conserving natural enemies. However, low populations of the main aphid predators (hoverflies and ladybird), could be attributed to the absence of aphids in the neem plots. Spiders, being a generalist predator on the other hand was high in the neem plots because of the availability of other sources of prey. This confirms that the neem treatment only had a minimal detrimental effect on the natural enemies, including the ladybirds and hoverflies. Other studies, also reported that, neem oil formulation was effective against *L. erysimi* and did not have any detrimental effect on its hoverfly predator, *Ischiodon scutellaris*; (Boopathi and Pathak, 2011). Application of aqueous neem seed kernel extract was effective in reducing the aphids' population on cabbage (Patel *et al*., 1996). Muhammad *et al*., 2013, reported a significant reduction in aphid population, increased yield and mild effect on the predators *Chrysoperla carnea,* when canola was treated with neem. Aline and Mauricio (2015), reported effective control of the cabbage aphid on kale using neem oil and kaolin oil.

This is contrary to the lambda-cyhalothrin treatment, which had no effect on the aphids, but had a detrimental effect on the natural enemies. This action, led to a continuous build-up of aphids in the lambda-cyhalothrin plots. This confirmed earlier observation in a field experiment in Ghana in which different formulations/trade names of labda-cyhalothrin, failed to control aphid on cabbage leading to low yields compared to plots sprayed with garlic, pepper (Zehnder *et al*., 1997, Fening *et al*., 2013, 2014). Amoabeng *et al*., 2013 also observed poor control of aphid on cabbage by Lambda Super® (lambda-cyhalothrin) in a field cage experiment. The ineffectiveness of these insecticides was attributed to the reduction of natural enemies; hoverflies, *Cheilomenes* spp. and spider and also resistance of this pest to lambda-cyhalothrin. Additionally, Devotto *et al*. (2007) reported that Lambda-cyhalothrin is a pyrethroid with broad-spectrum action, which could be harmful to non-target organisms such as natural enemies. Chlorpyrifos (organophosphate), though controlled *L. erysimi* than lambda-cyhalothrin, also had a negative effect on the natural enemies. There was also a slow build-up of *M. persicae* population throughout the sampling week for the major season. Reports have also shown that, *M. persicae* has developed resistance to several insecticides. These findings, concurs with work done by Karishniah and Mohan (1983) who reported that chlorpyrifos gave effective control and suppressed the population of mustard aphid and Rabea (2009) who reported resistance of *M. persicae* to chlorpyrifos, lambda-cyhalothrin profenofos, spinosad and deltamethrin. Notwithstanding, Organophosphates are broad spectrum insecticides and are known to be highly toxic to predators (Fernandez *et al*., 2010). For example, Chlorpyriphos EC, was found to be highly toxic to the maggots of *Ischiodon scutellaris* (Boopathi and Pathak, 2011).

Pepper and *alata samina* also reduced aphid pest populations than Lambda-cyhalothrin with minimal effect on the natural enemies. This observation confirmes earlier findings by Zehnder *et al*., (1997) and Fening *et al*., (2013) The ability of pepper to kill or repel pest, may be associated with the presence of capsaicinoid elements in the extract (Antonious *et al*., 2006; Fening *et al*., 2013). However, Habimana and Hakizayezu (2014) reported that, alkaloids from chilli (*Capsicum frutescens*) controlled aphids 100%. *Alata samina* has insecticidal properties and thus considered as an insecticidal soap. These soaps are composed of potassium salts of several fatty acids whose mode of action is not well understood but it is believed to disrupt pest's cellular membrane especially soft bodied insects resulting to loss of cellular contents, hence, death (Osborne and Henley, 1982).

Among the natural enemies present on the field during sampling, the hoverfly, ladybirds and spider were the most common and predominant, while *D. rapae* population was very low. The rate of parasitism observed, was very low and could not have contributed to reduction in aphid numbers. This finding however is contrary to work done by Gabrys *et al*., (1998) in cabbage fields in Poland, which recorded about 35% parasitism of cabbage aphids by naturally occurring *D. rapae*. This shows that, the predators accounted for the natural reduction in aphid numbers.

5.3 Effect of treatments on other insect pests

Other insect pest identified are known to be pest of cabbages and have been reported in other areas of Ghana where cabbage is cultivated. The findings of this study showed that neem effectively controlled the pests *P. xylostella*, *H. undalis* and to some extent *B. tabaci*. Azadirachtin which is the most abundant active ingredient in neem, is known to induce a physiological effect on insects by interfering with the synthesis and release of ecdysteroids which disrupts larval moulting in hemi- and holometabolous insects. It also interferes with pupation, eclosion of adults, and with reproduction (Mordue and Blackwell, 1993; Anibal and Condor, 2007). The effective control of these insects can be attributed to the diverse modes of action of azadirachtin present in neem. It could also be that, neem acts as a deterrent when sprayed to plants and also alters some properties of the cabbage plant such as the leave colour, that attracts *P. xylostella* and other insect pests, thus, detering the insect. In line with this, Gaby (1988) indicated that botanicals like neem extracts play an important role in altering the attractive properties of crucifer plants to *P. xylostella*. This finding is supported by previous work done by Begna and Damtew, (2015) which reported neem as the best botanical treatment in a field trial on cabbage in Ethiopia because it reduced pest number, increased yields and also gave a maximum economic return. Sow et al., (2013) recorded effective control of *P. xylostella* when neem was used as a treatment on cabbage. According to Lidet (2007) plots treated with Neem, showed the least *P. xylostella* number throughout the sampling weeks. Also, Prasannakumar *et al*., (2014) recorded effective control of *H. undalis* and aphids when cabbages were treated with neem seed powder extract and neem soap. Appiagyei (2010) reported that whiteflies were more susceptible to neem extracts than to karate (lambda-cyhalothrin).

The other botanical used in the study; pepper fruit extract also showed a significant effect on *P. xylostella*, *H. undalis* and *B. tabaci*. As earlier mentioned, the effect of this extract could be attributed to it hot nature or to the presence of capsaisinoid elements (Antonious *et al*., 2006; Fening *et al*., 2013). Other elements present in pepper extract include alkaloids, saponins and flavonoids (Habimana and Hakizayezu, 2014) all of which could be responsible for the control of these insect pests. Shazia *et al*., (2006), showed that pepper effectively reduced the incidence and severity of the *P. xylostella* leading to high number and percentage of marketable heads, compared to the control. Nguyen *et al*., (2014) also showed effective control of insect pests on cabbage, increased head diameter, head weight, and quality of cabbage using garlic and chili combination solution.

The insecticidal property of Alata samina on the other hand also had a considerable effect on the insect pests *P. xylostella*, *H. undalis* and *B. tabaci.* Alata samina is a local soap made from potash and its insecticidal property is attributed to the presence of potassium salts of several fatty acids which is believed to disrupt pest's cellular membrane, once it touches the insect (especially the larva forms, since they are soft bodied) leading to death.

On the other hand, synthetic insecticides-treated plots, recorded a constant build-up of *P. xylostella* populations throughout the two sampling seasons. Though there was considerable control of *H. undalis* to below damage levels, whitefly populations were also recorded at a very high level compared to the other treatments. Hill and Foster (2000), suggested that, synthetic insecticides will remain essential for the management of *P. xylostella* larvae since it feeds on the marketable portions of the crop. However, the insecticides used in this study; lambda-cyhalothrin and chlorpyrifos did not control *P. xylostella*, leading to devastating damage of crops. *P. xylostella* has been reported to be resistant to several groups of insecticides, making it difficult to control in the field (Branco and Gatehouse, 1997; Odhiambo, 2005; Eziah *et al*., 2009; Odhiambo *et al*., 2010). Therefore, high numbers recorded in the lambda-cyhalothrin and chlorpyrifos-treated plots is possibly due to the fact that, it must have developed resistance to these two insecticides. Moreover, *P. xylostella* has been reported to have acquired cross resistance to commonly used pyrethroids and multiple resistance to pyrethroids and organophosphates (Odhiambo *et al*., 2010). Several reports have also been made on the resistance of whiteflies to several groups of insecticides. High numbers also recorded during this study may also be attributed to insecticide resistance. Nevertheless, cross resistance to organophosphates by *B. tabaci* has been reported by Cahil *et al*., 1995. Ahmad *et al*., 2002 also observed resistance of *B. tabaci* population to organophosphates and pyrethroids. It is generally known that continuous usage of insecticides usually results in the emergence of insecticide resistance in insect pest and results gotten from this study would be the case. This is because, insecticides used in the study, are frequently applied on cabbage and other vegetables in Ghana for control of insect pests (Horna *et al*., 2008; Glover-Amengor and Tetteh, 2008; Afari-Sefa *et al*., 2015). Similarly, studies in East Africa reported that cases of resistance were found to be a result of intensive weekly insecticide application by farmers (Oduor *et al*., 1997; Cooper, 2002).

From the results, it can be observed that the botanicals and the insecticidal soap managed insect pest more effectively while maintaining a balance of nature compared to the synthetic insecticides. This is because, botanical derived extracts have the ability to prolong and alter the developmental stages of insect pests. Also, the observation in this study, confirms earlier reports that botanicals are generally safe to natural enemies and non-target insects (Charleston *et al*., 2006; Isman, 2006) and they are capable of managing insecticide-resistant pests of many crops (Amoabeng *et al*., 2013).

5.4 Effect of treatments on yield and quality

The result showed that neem rendered the highest yield. This confirms earlier work done by Baidoo and Adam. (2012). Sow *et al*. (2013) recorded increase in head size due to effective control of *P. xylostella* when neem was used as a treatment on cabbage. Control plots (plots sprayed with only water) had higher yield than lambda-cyhalothrin in the major season. This was likely due to high natural enemy abundance (spiders, ladybirds and hoverflies) which offered natural control as opposed to lambda-cyhalothrin. Inspite of the high numbers of natural enemies in the control plot, the attack by aphids was very severe, due to their large numbers, leading to very lower yields in the minor season. This shows that control by natural enemies only was inadequate and that botanicals such as neem and pepper will be necessary to reduce aphid populations and hence an improvement in yield.

Higher percentage of marketable heads was recorded in the neem plots followed by alata samina and pepper plots. Shazia *et al*. (2006), which showed that pepper extract effectively reduced *P. xylostella* population, leading to high number and percentage of marketable heads, compared to the control. Lidet *et al*. (2009) also reported improved cabbage yield and quality when neem was used against insect pests. In a similar study, neem seed extract was highly effective in protecting cabbage plants against insect pests leading to high yield quality compared to Karate (lambda-cyhalothrin) and water (Dzomeku *et al*., 2011). Other factors associated with the reduction in yield was damages caused as a result of insect feeding such as multiple head formation, virus-like transmitted disease incidence and severity (Fening *et al*., unpublished). Percentage multiple head formation was significant between the treatments for the minor season, where highest percentage was recorded in the control plots. This indicates that a management option is needed for the production of cabbage to improve on the yield. The least percentage was observed in the neem plots, and this is in line with findings that reported improved yield when neem was used as a treatment on cabbage (Baidoo and Adam, 2012; Sow *et al*., 2013). One of the damages associated with aphid attack was the incidence of a 'suspected' viral disease severity (Fening *et al*., unpublished). The severity of this disease was significant among the treatments for the minor season and highest severity was recorded in the control and pepper plots while neem recorded no disease at all. This implies neem was able to repel the major insect pest; aphids, transmitting this virus transmitted-like disease. This effect is attributed to the many modes of action possessed by the active component of neem; azadirachtin. Oseifuah (2015) also reported high virus transmitted-like disease incidence in sole cabbage plots with no treatment than cabbage plots intercropped with onion. This therefore supports the claim that, a management option is needed for the cultivation and production of cabbage in Ghana.

5.5 Effect of climatic factors on aphids

Climatic factors such as temperature, rainfall and relative humidity usually have an effect on the population dynamics of many arthropods especially insects (Nakata, 1995; Leite *et al*., 2005; Abbas *et al*., 2014). This study showed that temperature and rainfall had a significant negative correlation for the major and minor seasons on the aphid populations except relative humidity that had a positive correlation on the population. Other studies by Nasir and Ahmad (2001); Aheer *et al*. (2008), observed that temperature was positively correlated with aphid population while relative humidity played a negative role in fluctuating pest density. Significant negative correlation between aphid population and rainfall was also reported by Wains *et al*. (2008) in a related study.

Regression analysis, also showed no significant relation between the weather factors and the population of aphids from this study. This finding is in line with results by Leite *et al.* (2006) who reported no significant relation between climatic factors with aphids' population.

This study also revealed that a temperature range of 31 -35°C and a %RH of 26-48% was optimal for aphid population build up.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Indiscriminate use of insecticides by farmers engaged in the production of cabbage, have led to the development of resistant strains in so many insect pests. Detrimental effect on natural enemies and human, high insecticide residues, high production cost, are also problems associated with the use of synthetic insecticides. Other alternatives to synthetic insecticides such as botanicals, can be a way out to reduce these harzadous effects. Botanicals have been reported to have a low mammalian toxicity and environmental persistence, thus can be considered the most suitable in the management of insect pests on cabbage.

From this study, it is observed that, botanical insecticides and insecticidal soap efficiently cajulled aphids and other associated insect pests, while conserving their natural enemies, in the following order of decreasing efficacy; neem, alata samina, pepper. The effect of aqueous neem seed extract was greater than that of the other treatments, leading to very high yields and percentage of marketable heads compared with their synthetic insecticide counterparts. This therefore reveals that aqueous neem seed extract is an effective option for managing aphids on cabbage, and other associated insect pest. Due to the processes involved in extraction, purification and standardization, the use of commercially extracted neem products such as Neemazar® may also be more expensive than synthetic insecticides. Thus, it may be economically rewarding for smallholder farmers, especially in developing countries to use neem seed extract due to the ready availability of plant materials and the ease in preparation.

Pepper is used as a spice for preparation of food, while neem is often boiled and taken for medicinal purposes. Since cabbage is often eaten raw, using neem or pepper as a management option for aphids will contribute to food safety and further prevent contamination of produce by insecticide residues.

The studies also showed that, most of the insect pests on cabbage have become resistant to the synthetic insecticides; chlorpyrifos and lambda-cyhalothrin.

The report of *L. erysimi* in Ghana for the first time is very important, as this will help in its management by integrating appropriate strategies. It also appears this insect is transmitting the 'suspected' viral disease causing a great loss in the production of cabbage.

The climatic factors had a negative effect on the population of aphids.

6.2 Recommendation

The following are recommended based on the results gotten from the study:

- Further investigation should be carried out on the 'suspected' viral disease on cabbage, for identification and to acertain aphids as its vector, for efficient management.
- Neem should be used as an alternative to synthetic insecticides for effective management of insect pests, and also for food safety
- Low concentrations of alata samina is recommended for use on cabbage to control insect pest, as high doses may be phytotoxic to plants.
- Organoleptic evaluation of neem and alata samina treated cabbages should be carried out, to determine if they have undesirable flavours

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APPENDICES

Appendix 1: Differences between insect numbers for the major and minor season (t-test)

Insects	Major season (mean)	Minor season (mean)	t-value	p
L. erysimi	277±99.31	120±46.58	1.43	0.184
M. persicae	36±23.24	10±6.62	1.08	0.323
B. borbonicus	5±1.970	3±1.286	0.89	0.393
Cheilomenes sp	3±1.187	0.135±0.072	2.63	0.046
Spiders	4±1.057	4±0.951	0.30	0.774
D. rapae	1±0.165	0±0	1.35	0.208
P. xylostella	25±7.48	30±18.44	0.27	0.795
H. undalis	1±0.175	2±0.690	-1.30	0.243
B. tabaci	2±0.767	128±15.893	-7.91	<0.001

Appendix 2: Harvested cabbage heads for the different treatments

Cabbage heads from lambda-cyhalothrin (A) and chlorpyrifos (B)-treated plots

Cabbage heads from pepper (A) and neem (B)-treated plots

Cabbage heads from control plot (A) and alata samina-treated plot (B)