EXPLOITING THE INSECTICIDAL POTENTIAL OF THE INVASIVE SIAM WEED, *Chromolaena odorata* L. (ASTERACEAE) IN THE MANAGEMENT OF MAJOR PESTS OF CABBAGE, *Brassica oleracea* var *capitata* AND THEIR NATURAL ENEMIES FOR ENHANCED YIELD IN THE MOIST SEMI-DECIDUOUS AGRO- ECOLOGICAL ZONE OF GHANA

BY

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DECLARATION

This is to certify that this thesis, with exception of references to other works which have been duly acknowledged, is the results of research work undertaken by me, Godfred Nwosu Ezena, at the Forest and Horticultural Crops Research Centre (FOHCREC) towards the award of Master of Philosophy (M. Phil.) degree in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS), University of Ghana, Legon.

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DEDICATION

I dedicate this thesis to my dear wife, Mrs. Helena Ezena and my lovely daughters, Irene Ifeoma Adomah Ezena and Jessica Nkechi Dansowaa Ezena, for their sacrifices during this course. I was away and denied you of my comfort, yet you prayed for me to endure all hardships to complete this programme. I say I would forever be grateful and God bless you!

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ARPPIS	African Regional Postgraduate Programme in Insect Science
Bt	*Bacillus thuringiensis*
DBM	Diamondback moth
DDT	Dichlorodiphenyltrichloroethane
EC	Emulsifiable Concentrate
FOHCREC	Forest and Horticultural Crops Research Centre
GH₵	Ghana cedis
GMT	Greenwich Meridian Time
Ha	Hectare
IPM	Integrated Pest Management
NPM	Non- pesticide management
PSBs	Pods Sucking Bugs
SE	Standard error
Ton	Tonne
TRT	Treatment
US$	United State Dollars
WAT	Weeks after transplanting
WHO	World Health Organization

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ABSTRACT

Cabbage is an important crop for many smallholder farmers in Africa and Asia, due to its nutritional and financial benefits. It is one of the popular vegetables consumed and cultivated by both urban and rural dwellers in Ghana. The production of cabbage in Ghana, however, is faced with numerous constraints especially insect pest infestations. Farmers have limited control options and therefore resort to the use of synthetic insecticides. Indiscriminate use of these insecticides has led to insect pest resistance problems, and also toxic residues in cabbage heads, posing high risk to humans, animals and the environment. Botanicals, which are derived from plant products are reported to be effective against many insect pests and are considered cheap, easily degradable and environmentally safe. Field experiments were carried out to determine the insecticidal potentials of siam weed, *Chromolaena odorata* L. at different rates (10, 20 and 30 g/L) in the management of the major pests of cabbage and its effect on their natural enemies during the major and minor seasons of 2014. The treatment consisted of three doses of *C. odorata* (10, 20 and 30g/L of water), 50 g/L of neem seed extract (as standard botanical), a conventional insecticide, Sunhalothrin® (with active ingredient Lambda cyhalothrin, EC) and tap water as a control. The treatments were laid out in randomized complete block design (RCBD) with three replications. The numbers of insect pests were recorded weekly on eight innermost cabbage plants per plot from transplanting until maturity. At maturity, cabbage heads obtained from each treated plots were counted and weighed and then classified as marketable or unmarketable depending on the level of damage. Cost-benefit analyses of the different management options were also carried out. The diamondback moth (DBM), *Plutella xylostella* L. occurred only during the minor rainy season. The three rates of *C. odorata* had significantly lower number of aphid, *Brevicoryne brassicae* L. as compared to the Sunhalothrin. The 10 and 20g/ L of *C.*

odorata sprayed plots recorded the highest build up of natural enemy populations as compared to 30g/ L of *C. odorata* and Sunhalothrin during the major rainy season. The cabbage plots sprayed with neem seed extract and siam weed extract (especially 10 and 20 g/L of water) had the highest yield, followed by the 30g/ L *C. odorata* and Sunhalothrin treated plots and the control The study also indicated that, the neem seed extract treated plots had the highest cost- benefit ratio followed by 20, 10 and 30g/L *C. odorata* treated plots, with the Sunhalothrin treated plots being the least. The findings from the current study, therefore, attest to the potential of 10 and 20g/ L of *C. odorata* as effective and economically feasible option for the management of insect pests of cabbage and other related vegetables, especially in smallholder farms and backyard gardens and other organic farming systems.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Cabbage, *Brassica oleracea* var. *capitata* (L.) originated from the Mediterranean Region, Southern England, Wales and Northern France (Norman, 1992). It belongs to the family Cruciferae and is cultivated from the arctic to sub-tropic and at higher altitudes in the tropics as well as in the tropical lowlands on the West African coast (Hill, 1983).

Cabbage is a very important vegetable produced in mostly the southern parts of Ghana and is consumed by both the rural and urban populations (Obeng-Ofori and Ankrah, 2002). The crop has replaced many indigenous green vegetables and is now cultivated all year round on mainly rented lands in the urban centers, and near streams in the peri-urban and rural areas (Timbilla, 1997; Timbilla and Nyarko, 2004; Fening *et al.*, 2013, 2014). The cultivation of cabbage provides a good source of employment for both rural and urban dwellers (Norman, 1992). Furthermore, middlemen who purchase the vegetable from farms and send it to the urban centres as well as transport operators who convey the heads to the market centres, all obtain their source of livelihood from the crop (Asare- Bediako *et al.*, 2010).

Cabbage has traditionally been used to cure certain ailments as well as for food. It has anti-inflammatory property and contains chemicals which can prevent cancer (Lin, 2008). The ancient Greeks used fresh white cabbage juice to relieve sore or infected eyes and juice from the cabbage stem is a good remedy for ulcers (Norman and Shealy, 2007). Traditionally, the Romans and Egyptians drink cabbage juice before big dinners to prevent intoxication from alcohol (Lin, 2008). Cabbage seeds are also believed to prevent hangovers (Norman and Shealy, 2007).

1.2 Problem statement

Cabbage production, like many other crops is faced with numerous constraints. These include high cost of inputs such as pesticides, seeds, fertilizers and also attack by insect pests and diseases (Fening *et al*., 2013, 2014). Among these production constraint, insect pests and diseases are the most important factors that reduce the quality and marketable yield of cabbage (Timbilla and Nyarko, 2004). Insect pests and diseases can devastate cabbage to a nearly zero yield. For instance, the diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae) is the most important pest of cabbage in Ghana (Obeng-Ofori and Ankrah, 2002; Timbilla and Nyarko, 2004). This insect is one of the greatest threats to crucifer production in the tropics causing over 90% crop losses (Charleston, 2004). The cabbage webworm, *Hellula undalis* L. (Lepidoptera: Pyralidae) and cabbage aphids, *Brevicoryne brassicae* L. (Hemiptera: Aphididae) are also important pests of cabbage in Ghana (Ninsin, 1997).

Moreover, damages caused by these insect pests have over the years been reduced by various synthetic insecticides which are applied at different stages of the plant's growth (Ninsin, 1997). It is well established that, pesticides play a major role for the production of adequate and high yielding food, especially vegetables for an increasing world population through the control of insects and insect-borne diseases. Many synthetic insecticides are however, toxic and persistent (Kluive, 1981). These synthetic insecticides cause toxicological and environmental problems which include toxic residues in food, soil, water, adverse effects on non-target insects and other beneficial organisms, as well as the development of resistant strains in insect pests (Ninsin, 1997; Amoako, 2010; Fening *et al.*, 2013). The indiscriminate and improper use of synthetic insecticides has been an issue of much concern to consumers (Fening *et al.*, 2013; Fening, 2013). Typical examples of insecticides used are Polythrine C® and Cypercal 50 EC® (Barbara, 1993; Amoako, 2010).

1.3 Justification

Vegetable farmers frequently apply synthetic insecticides to manage DBM, cabbage aphid and other prevalent insect pests of cabbage (Grzywacz *et al*., 2010; Gerken *et al*., 2001; Macharia *et al*., 2005) because they are quick in action and are easy to apply and less labour intensive (Weinberger and Srinivasan, 2009). There has been an increase in the resistance of DBM and other insect pests of cabbage to insecticides in recent times, making their management difficult (Obeng-Ofori and Ankrah, 2002; De Cássia Seffrin *et al*., 2010). Synthetic insecticides have also been associated with health hazards to humans and animals, environmental pollution and are unavailable to many peasant farmers such as those in the Ghana's rural communities (Devanand and Rani, 2008, De Cássia Seffrin *et al*., 2010; Fening, *et al*., 2013). Synthetic insecticides are often mishandled and misapplied especially by inexperienced farmers (Ntow *et al*., 2006; Coulibaly *et al*., 2007; Fening *et al*., 2013).

In order to avoid the negative impacts of these synthetic insecticides, alternative approaches to managing pests of cabbage and other vegetables have to be considered (Ntow *et al*., 2006, Coulibaly *et al*., 2007; Fening *et al*., 2013; Amoabeng *et al*., 2013). Botanical insecticides can be a good option to promote sustainable pest management because they have lower environmental impact than synthetic insecticides (Devanand and Rani, 2008; Rath and Gopalakrishnan, 2006). However, botanical insecticides such as pyrethrum and azadirachtin are relatively expensive and difficult for most smallholder farmers to obtain (Amoabeng *et al.*, 2013). To provide a viable alternative for resource- poor farmers, botanical insecticides must be based on plant materials that are cheap and readily available and can simply be prepared rather than requiring organic solvents and complex apparatus (Fening *et al.*, 2013). Also, extracts from plant materials have to be benign to natural enemies in order to avoid secondary and resurgent pests, as well as having low phytotoxicity whiles protecting yields (Fening *et al.*, 2013). Though simple, plant extracts are commonly promoted for use in home gardens, so there is growing interest for use by farmers in developing countries (Amoabeng *et al.*, 2013).

Some plant species which have useful insecticidal properties are in the families of Meliaceae, Rutaceae, Asteraceae, Piperaceae, Compositae, Lamiaceae, Euphorbiaceae, Combretaceae and Annonaceae (Amoabeng *et al.*, 2013). Some of these species are also considered as weeds in and around farms (Devanand and Rani, 2008). Pest control using local materials offers farmers the opportunity to reduce production costs, as the plants often grow wild in and around farms and so can be obtained with little effort and zero or minimal cost (Amoabeng *et al.*, 2013).

Siam weed, *Chromolaena odorata* (L.) (Asteraceae), an invasive shrub is believed to have originated from South America and the Caribbean (McFadyen, 1988). It was first reported in Ghana in 1969 (Hall *et al.*, 1972) and has since spread to cover about 60% of the land area of the country (Timbilla and Braimah, 1996). It is particularly, prominent in areas with an annual rainfall of about 2000 mm and has become a major weed of arable land and plantation crops, forests and rangelands. *Chromolaena odorata* grows very fast and smothers other vegetation beneath it by forming dense thickets or canopies that are difficult to penetrate. The plant is known by several local nicknames such as ‘Acheampong’, ‘Busia’ and ‘Abaafo’ across its range in Ghana (Timbilla and Braimah, 1996).

The introduction of *C.odorata* has brought new challenges to bear on agricultural productivity in Ghana. For instance, the management of *C. odorata* in plantation crops such as cocoa, oil palm and citrus is reported to contribute to about a third of the cost of production of such plantations (McFadyen, 1988). The high cost of plantation maintenance and other problems associated with the management of this weed have forced some farmers to abandon their plantations (Timbilla and Braimah, 1996). *Chromolaena odorata* has also contributed significantly to the recent forest fires in the country because it produces large quantities of dry leaf litter, stems and twigs that contain chemicals which act as fuel for fires (Braimah and Timbilla, 1991).

However, *C. odorata* when utilized as a botanical has proven to be effective against pods-sucking bugs (PSBs) infestation in the savannah region of Northern Nigeria, and this, can sustain greater cowpea yield (Degri *et al*., 2013). *Chromolaena odorata* can therefore serve as a better alternative to synthetic insecticides usage for managing the populations of pod sucking bugs (PSBs) on cowpea. It has been considered advantageous, because they are readily available and bio-degradable bio-insecticides which are friendly or safe to the applicators, farmers, consumers and the environment (Degri *et al*., 2013).

However, some botanical insecticides may also adversely affect beneficial insects (Buss and Park-Brown, 2002; Dubey *et al*., 2011). For example, Amoabeng *et al*., (2013) have indicated that 30 g/L of *C. odorata* applied in controlling DBM larvae in the field among other botanicals was effective in reducing the pest population. However, this rate of *C.*

odorata was found to significantly reduce the population of natural enemies in the field (Amoabeng *et al*., 2013). Fening *et al*., (2011), also cautioned that, higher concentrations of botanicals could possibly have some detrimental effect on natural enemy populations because their numbers reduced with increasing concentrations. Hence, the need to optimize the dose of crude extract from *C. odorata* for effective control of major pests of cabbage with minimal or no adverse effect on the natural enemies of these pests and other non-target organisms.

1.4 OBJECTIVES

1.4.1 Main objective

The main aim of this study was to optimize the dose of *Chromolaena odorata* leaf extract to manage the major pests of cabbage and also ensure the survival of their natural enemies.

1.4.2 Specific objectives

1. To assess the performance of three rates of crude extracts of siam weed to manage insect pests of cabbage.
2. To ascertain the effect of the different rates of the siam weed extract on the natural enemies and other non-target organisms in the field.
3. To determine a cost- benefit analysis for the use of siam weed as a local botanical insecticide.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 History of cabbage as an edible leafy vegetable

The cabbage plant is native to the mediterranean region of Europe and it is somewhat similar in appearance to a leafy canola plant (Andongma, 2010). The cultivation of the plant started soon after the domestication of plants began (Sinnadurai, 1992).The people of the Mediterranean region began growing the first ancient cabbage plant as a leafy vegetable. Because leaves are the part of the plants which are consumed, plants with the large leaves were selectively propagated (Obeng- Ofori, 1998). This resulted in large and larger-leafed plants slowly being developed as the seed from the largest-leafed plants were favoured. By the 5th century B.C., continued preference for ever-larger leafed plants had led to the development of the vegetable we now know as Kale. Kale is known botanically as *Brassica oleracea* variety *acephala* which translates to mean cabbage, of the vegetable garden without a head. Kale has since been grown as a leafy vegetable for thousands of years (Baldwin, 1995).

The crop was probably introduced by the British into Ghana (Sinnadurai, 1992). There is no record of the time of its introduction but the crop was grown on a small scale around 1940. It is still not a popular crop in the rural areas. It is a popular crop around urban towns and cities where the bulk of the crop is produced for Ghanaians and foreigners in the country (Obeng- Ofori *et al*., 2007). Cultivars such as Copenhagen Market, Drumhead, Suttons Tropical, Japanese Hybrid cabbage, Golden Acre, Suttons Pride of the Market, KK Cross, Oxylus and Marion Market are suitable for production in Ghana (Obeng- Ofori *et al*., 2007).

2.2 Description and agronomy of the cabbage plant

Cabbage (*Brassica oleracea* var *capitata* L.) is the most important vegetable in the family Cruciferae. The edible portion is called the head which is made up of many overlapping thin smooth leaves covering a small terminal bud (Sinnadurai, 1992). The head forms halfway through the growth of the plant and thus is not seen in young seedlings. When the head is removed, buds arise in the axils of the lower leaves and these may form small heads called "cabbage sprouts" or multiple heads and do not have any commercial market value (Obeng- Ofori *et al*., 2007).

Cabbage could be described as a very large terminal bud with foreshortened stem and tightly packed in rolled leaves (Plate 1). If flowering is allowed to occur there are appropriate internodes elongations terminating in the formation of an inflorescence. The head shape may be pointed or round and the leaf colour and shape are variable (Rice *et al*., 1993; Andongma, 2010).

Plate 1: The cabbage plant.

Cabbage like other brassicas is grown from the seed. The seeds can both be sown in a seedbed and later pricked - out on to a nursery bed or sown directly in the nursery bed (Schmutterer, 1992). Close spacing of the seedlings in the nursery can cause the hypocotyls to elongate and such seedlings will not stand erect when transplanted in the field. Close spacing may also cause damping - off disease which enhances insect infestation. Seedlings may be ready for planting about 21 to 30 days after nursing. Nursery beds should be manured and sterilized before sowing the seed. Shade the nursery immediately after sowing and remove the shade after the seedlings have emerged. Hardening of seedlings before planting is essential when the crop is to be grown under rainfed conditions. Spacing in the field will depend on the cultivar (Obeng- Ofori *et al*., 2007).

Cabbage is a cool season crop which prefers a cool moist climate with a monthly average temperature of 15^{o}C to 22^{o}C (Hill, 1983). When the temperature is high, small heads are produced. However, varieties have been bred which produce large heads under high temperature in the warm tropics. In the warm tropics like West Africa, the head will crack when mature and eventually deteriorate without flowering. Cabbage as a vegetable is treated as an annual crop. In West Africa, the growing season is during the cool months from July to September in the South as a rain fed crop and from November to January as an irrigated crop. It can be grown during the same period in the north. In the forest zone, three crops a year have been in low - lying areas with supplementary irrigation (Hill, 1983; Obeng- Ofori *et al*., 2007).

2.3 Cabbage production and their constraints in Ghana

Cabbage is an important exotic vegetable grown on both large and small scale farms in Ghana (Obeng- Ofori, 1998). In Ghana, it is a popular vegetable among urban and peri-urban dwellers (Timbilla and Nyarko, 2004). Fresh vegetable production farms for city residents are located on outskirts of cities or cleared areas in highlands accessible from the cities. Production of healthy looking and damage free cabbage for wealthy city dwellers are important considerations in cultivation of cabbage (Talekar and Shelton, 1993). Insecticides are frequently used for the control of insect pests. The sole reliance on insecticides for the control of insect pests can result in the rapid build- up of resistance (Andongma, 2010).

Cabbage production can be a very profitable activity, with a quick return on investment (Mochiah, *et al*., 2011a). The total harvesting period for cabbage in the field varies from 3 to 4 months, but some varieties can be harvested in about 70 days after transplanting (Obeng- Ofori *et al*., 2007). There is no seed recycling but the total seed cost for cabbage production represents only 5% of the farmers' total costs (Mochiah *et al*., 2011a). Meanwhile, fertilizers and insecticides together account for 17% of the total expenses and labour cost is 60%, with a high proportion being family labour (Horna *et al*., 2007). The main activities are nursery management, land preparation, transplanting, weeding, watering and harvesting. Cabbage production tends to be very intensive with high levels of pesticides and fertilizers applied which can run off into drinking water sources (Obeng- Ofori *et al*., 2007). Producers usually use low quality water from drains, shallow wells and streams to irrigate their fields (Horna *et al*., 2007). Cabbage marketing and prices are determined by the seasonality of demand (Obeng- Ofori *et al*., 2007). Cabbage demand peaks around December festivities and continues throughout the dry season (Mochiah, *et al*., 2011b). The compact head of Oxylus is the most preferred variety and transports and also stores well.

Lack of variety diversity however, is a problem that needs to be addressed (Obeng- Ofori, 1998; Horna *et al.*, 2007).

Although cabbage has enormous benefits to the growth of humans and the nation as a whole, its production is associated with a lot of problems. These include difficulty in land acquisition; high cost of inputs such as fertilizers; labour; lack of good water for irrigation; high weed infestation and attack by diseases and insect pests (Obeng- Ofori, 1998). Prominent among these problems in Ghana is pest attack. These pests include aphids, *Brevicoryne brassicae*, Bagrada bug, *Bagrada hilaris*, flea beetles, *Phyllotreta* sp., diamondback moth, *Plutella xylostella* and cutworm, *Agrotis* sp. (De Lannoy, 2001). The most devastating pest that causes severe damage in cabbage production is the diamondback moth (DBM) (Kwarteng and Towler, 1994). Pest infestation normally leads to reduction in market value and in some cases total crop failure (Joel, 1994).

2.4 Nutritional and health benefits of cabbage

Cabbage is a good source of protein, carbohydrates, calcium, iron, carotene, thiamine, riboflavin, niacin, as well as vitamin C (De Lannoy, 2001). Cabbages can also serve as food for cattle, pigs and other farm animals. Mashed and juiced cabbage used in poultices has helped to treat boils, warts, pneumonia, appendicitis and ulcers (Hatfield, 2004).

Tindall (1983) listed the nutritive components of cabbage leaves per 100g edible portion as follows: water – 93ml, calories – 23J, protein – 1.5g, fat – 0.2g, carbohydrates - 4g, fibre – 0.8g, calcium – 40mg, iron – 0.5, vitamin potency – 30iu, thiamine –0.05mg, riboflavin – 0.05mg, niacin – 0.3mg and ascorbic acid – 40mg.

Cabbage has been used daily in dishes as a relish and has curative benefits such as in the control of bronchitis, cataracts, diabetes, Cronhn's disease, diverticular diseases, heart attack and hypertension (Reuben *et al*., 2006).

A study in Utah revealed that those who ate more cruciferous vegetables had a much lower risk of colon cancer (Lin, 2008). On the side of caution, however, consuming excessive amount of cabbage may contribute to thyroid problems, possibly goiter (Nisit *et al*., 2006). A well-known remedy for healing peptic ulcers is drinking cabbage juice (Allen and Allen, 2009). It has been known for the past 20 years that phytonutrients work as antioxidants to disarm free radicals before they can damage DNA cell membrane and fat containing molecules such as cholesterol (Norman and Shealy, 2007). Now, new research is revealing that phytonutrients in crucifers such as cabbage work at a much deeper level (Nisit *et al*., 2006). These compounds actually signal our genes to increase production of enzymes involved in detoxification (Allen and Allen, 2009). Recent studies show that those eating more cruciferous vegetables have a much lower risk of prostate, colorectal and lung cancer-even when compared to those who regularly eat other vegetables (Lin, 2008).

2.5 Cabbage production as a source of employment

Cabbage provides a source of livelihood to all individuals who are engaged in its production from its cultivation till it gets to the final consumer (Sinnadurai, 1992; Asare-Bediako *et al.,* 2010).

2.6 Diseases of cabbage

Cabbage is not only affected by insect pests but also diseases. Although there are many diseases that affect cabbage, only a few are prevalent or cause much damage (Rice *et al.*, 1993). Diseases in plants occur when a pathogen is present, the host is susceptible, and when the environment is favourable for the disease to develop (Guerena, 2006). Altering any one of these three factors may prevent the disease from occurring. Organisms responsible for plant diseases include fungi, bacteria, nematodes, and viruses (Obeng- Ofori *et al*., 2007). If these organisms are present, then the manipulation of the environment and the host may make it less susceptible and help it to be more sustainably managed, causing the diseases on cabbage and other brassica crops (De Lannoy, 2001; Obeng- Ofori *et al.*, 2007).

Some common diseases of cabbage and other brassicas include; black rot and soft rot which are caused by bacteria, *Xanthomonas campestris* and *Erwinia carotovora* respectively. These bacteria occur as a result of infection on seeds, on crop residue in the field, or on weeds in or near the field and under favourable weather conditions. These diseases cause large V-shaped spots on the edges of the leaves. These spots have a yellow margin, and the veins in the spots are black. In severe cases, the whole leaves may be blighted causing great reduction in yield (Guerena, 2006).

Other diseases of cabbage are mostly caused by fungi. These include; Downy mildew, Fusarium wilt, Damping off and Alternaria leaf spot. Most of these diseases are favoured by wet weather conditions and have caused stunted growth in the crop and also caused large grayish- black ringed spots on the leaves down to the stem, making the crop unmarketable (Ninsin, 1997).

2.7 Insect pests and other arthropods

Like other brassicas, cabbage has a wide spectrum of pests. The continuous cultivation of the crop has led to the proliferation of insect pests such as *Hellula undalis* (Fab.) (Lepidoptera: Pyralidae), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) and *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae) (Timbilla, 1997). Obeng- Ofori *et al*., (2007) have listed the major types of insect pests of cabbage in Ghana (Table 1). These include aphids which transmit viral diseases and leaf eating caterpillars, which can completely defoliate plants during severe attacks.

Table 1: Some major insect pests of cabbage in Ghana

Scientific Name	**Common Name**	**Order**	**Family**
Plutella xylostella	Diamondback moth	Lepidoptera	Plutellidae
Brevicoryne brassicae	Cabbage Aphid	Hemiptera	Aphididae
Hellula undalis	Cabbage webworm	Lepidoptera	Pyralidae
Athalia sjostedti	Cabbage sawfly	Hymenoptera	Tenthredinidae
Phyllotreta spp.	Cabbage flea beetle	Coleoptera	Chrysomelidae

Source: Obeng- Ofori *et al*., (2007).

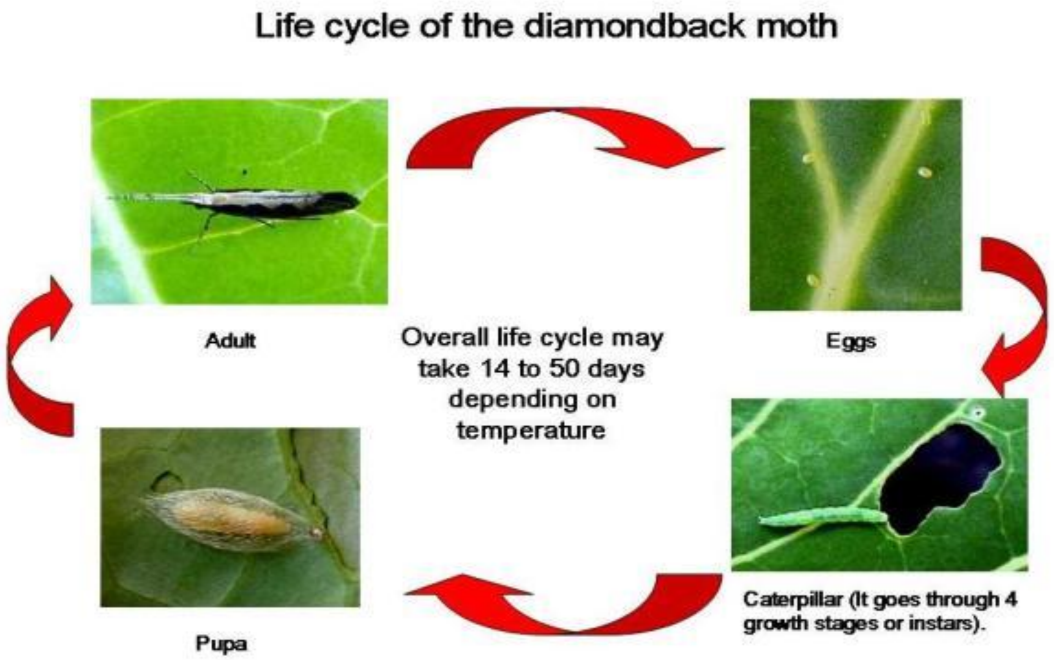
Other pests of cabbage reported in Ghana include the cabbage looper, *Trichoplusia nii*, the whitefly, *Bemisia tabaci* and the variegated grasshopper, *Zonocerus variegatus* (Mochiah *et al.*, 2011b; Fening *et al.*, 2011; Baidoo *et al.*, 2012). In 1970, Nigeria declared *Z. variegatus* a major pest and subsequently it had become a problem in Cote D' Ivoire, Ghana, Congo, Benin, Uganda, Senegal and Burkina Faso (Modder, 2004).

2.7.1 Diamondback moth, *Plutella xylostella* (L.)

Plutella xylostella is one of the most important pests of cruciferous crops throughout the world, and can cause serious economic losses if not controlled (Talekar and Shelton, 1993). In the warm, humid tropics, this insect breeds throughout the year, and can have more than ten generations annually. The destructiveness of DBM, coupled with the fact that it has the capacity to develop resistance very rapidly to any chemical control measure used singly, has made this pest the focus of IPM research in many parts of the tropical world. Practically, all the available methods and pest control technologies have been tried at some time or another for the management of DBM (Glare and O'Gallagham, 2000). The global cost of controlling this pest has recently been estimated between 4 and 5 billion US dollars (Zalucki *et al*., 2012).

2.7.1.1 Biology

Life cycle of diamondback moth is dependent upon temperature, and typically it completes its life cycle in about 25-30 days (Harcourt, 1957)(Plate 2). It is not known whether any of the life stages of diamondback moth undergoes diapauses or hibernate (Talekar and Shelton, 1993).



Source: A. M. Varela. Icipe

Plate 2: Life cycle of diamondback moth.

2.7.1.2 Egg stage

The egg is minute, yellowish white to yellowish green cylindrical to oblong with average dimensions of 0.48 x 0.25mm (Bhallaa and Dubey, 1986). The incubation period ranges from three to six days depending on the temperature (Talekar and Shelton, 1993).

2.7.1.3 Larval stage

The larvae are gray-green with a dark head in the first three instars and green with greenish brown head in the final instars, measuring 10-12mm in length and moderately stout, and smooth with short scattered hairs (Bhallaa and Dubey, 1986). The larval body form tapers at both ends, and a pair of protruding prolegs from the posterior end, forming a distinctive "V" shape and the prolegs are five in pairs (Harcourt, 1957). The diamondback moth has four instars: the range of days per instar is 3-7; 2-7; 2-8, and 2-10 for the 1st - 4th instar (Talekar and Shelton, 1993). Overall, length of each instar rarely exceeds 1.7, 3.5, 7.0, and

11.2 mm, respectively, for instars 1 through 4. Mean head capsule widths for these instars are about 0.16, 0.25, 0.37, and 0.61 mm (Harcourt, 1957).

The first instar larvae initially wonder over the leaf surface and feed as the miners, whereas older larvae feed from the lower leaf surface by scraping the epidermis of the crucifer plants and usually consume all tissue except the wax layer on the upper surface, thus creating a "window" in the leaf (Bhallaa and Dubey, 1986; Talekar and Shelton, 1993). The fourth instar larvae, consume the largest quantity of leaf tissue (Salinas, 1986). At the slightest disturbance, the larvae wriggle rapidly and drop down from the leaf, suspending themselves by silken threads (Bhallaa and Dubey, 1986).

2.7.1.4 Pupal stage

The mature caterpillar forms a loose silken cocoon. As a result, its body becomes shortened longitudinally but remains active (Bhallaa and Dubey, 1986). The mature pupae are 6mm long and light in colour. The pupal stage is between 7 to 11 days (Salinas, 1986). The newly formed pupa is yellowish green, but in a day or two it becomes brown in color until the time of adult emergence (Bhallaa and Dubey, 1986).

2.7.1.5 Adult stage

The adult is a small, slender, grayish-brown moth with pronounced pair of antennae. It is about 10-12 mm long, and marked with a broad cream or light brown band along the back. The band is sometimes constricted to form one or three light-coloured diamonds on the back when in rest position, which is the basis for the common name of this insect. When viewed from the side, the tips of the wings turn upward slightly. Adult males and females live about 12 and 16 days, respectively (Harcourt, 1957), and for 3 to 6 days without food and for 11 to 16 days provided with food (Salinas, 1986). Adults emerge during the evening and rarely in the morning hours. Females deposit eggs for about 10 days. Some moths may be weak fliers, but populations are known to migrate long distances (Talekar and Shelton, 1993). However, they are readily carried by the wind (Harcourt, 1957).

The male moth is dark brown with a pattern of three consecutive white diamonds on its back. The female moth is tan coloured and its diamond patterns are less distinct than those of the male (Borror *et al*., 1992). Adults are active at dusk and throughout the night. During the day if plants is disturbed the moth would be seen flying from their resting places (Talekar and Shelton, 1993).

Salinas (1986) reported the adults started copulating almost immediately after emerging from the pupae because the females produce a strong sex pheromone, which attracted the male. The individuals copulating pair face opposite directions and hang downwards with the female above. Mating lasts one to two hours with the females mating only once. Oviposition begins in the evening; the majority of the eggs are laid before midnight with peak oviposition occurring between 19:00-20:00 hours (Talekar and Shelton, 1993). The ratio of eggs laid on the upper and lower leaf surfaces is approximately 3:2 and very few eggs laid on stems and petioles (Harcourt, 1957). Eggs are laid preferentially in the cavities of leaves rather than on the smooth surface. Temperature, trichomes and waxes on leaf surface all influence oviposition (Talekar and Shelton, 1993).

The oviposition period lasts three to ten days depending on environmental conditions and peak oviposition occurs on the first day of emergence (Salinas, 1986). The fecundity of diamondback moth depends on many factors including genetic and nutritional condition of the larvae, morphological nature of the host plant, climatic conditions, and the presence or absence of host plants for oviposition (Salinas, 1986). Fecundity as low as 18 eggs, and as high as 306 eggs per female was reported by some workers (Chelliah and Srinivasan, 1986; Talekar and Shelton, 1993). The incubation period is influenced mainly by temperature and lasts 5 to 6 days (Talekar and Shelton, 1993).

2.7.1.6 Ecology of Diamondback moth

Diamondback moth occurs wherever crucifers are grown and is believed to be the most universally distributed of all Lepidoptera (Talekar and Shelton, 1993). There are numerous insects, which, like diamondback moth have a worldwide distribution. These cosmopolitan insects have certain common characteristics, which enable them to survive in the varying climatic conditions present over wider areas of their distribution. Besides, the potential to colonize under varying conditions, their strong dispersal or migrating capacity is indispensable to the increase of their distribution range (Chu, 1986). Although the origin of diamondback moth is not clear, judging from its close relationship with the cruciferous plants it is assumed that this insect originated in Asia Minor (Talekar and Shelton, 1993). There the moth further spread to other areas with the increase of cultivation of cruciferous vegetables.

Generally, the strong flight ability of the moth helped its distribution to even wider areas (Harcourt, 1957). This moth can remain in a continuous flight for several days and cover distance of 1000 Kms per day (Talekar and Shelton, 1993). Wind is reported to be a major factor in diamondback moth migration from one area to the other (Chu, 1986; Honda, 1992;

Talekar and Shelton, 1993). Honda (1992) suggested that density of source population, meteorological conditions when the adults take off, the physiological condition of the migrants and the temperatures of the upper air in which they migrate affect diamondback moth migration. Seedlings contaminated with diamondback moth were reported as sources of infestation in the United States (Talekar and Shelton, 1993). The presence of crucifers throughout the year in the tropics and subtropics allows the pest to be active throughout the season and hence the simultaneous occurrence of all stages of the insect. The mechanism of its occurrence in the temperate areas where crucifers are not found year round is not clearly known (Talekar and Shelton, 1993).

Diamondback moth larvae only feed on plants in the family Cruciferae, which contain mustard oil and their glycosides (Hillyer and Thorsteinson, 1971). Nayar and Thorsteinson (1963) stated that the glucosides sinigrin, sinalbin, and glucocheirolin produced by crucifer plants are important to stimulate diamondback moth feeding. Virtually, all cruciferous vegetables are attacked by diamondback moth including cabbage (*B. oleracea*. var. *capitata*), broccoli (*B. oleracea* var. *italica*), cauliflower (*B. oleracea*. var. *botrytis*), collards (*B. oleracea* var. *acephala*), kale (*B. oleracea* var. *alboglabra*), kohlrabi (*B. oleracea* var. *gongylodes*), mustard (*B. juncea*), radish (*Raphanus sativus* L.), turnip (*B. rapa var. pekinesis*), Chinese cabbage (*B. rapa* cv. gr. *pekinensis*), watercress (*Nasturtium officinale* R. Br.), and Brussels sprouts (*B. oleracea* L. var. *gemmifera*) (Capinera, 2001). Diamondback moth also feeds on many different cruciferous weeds, including yellow rocket, *Barbarea vulgaris*; shepherds purse, *Capsella bursa-pastoris*; pepper weed, *Lepidium* spp.; and wild mustards, *Brassica* spp., which serve as important alternate hosts for the pest, especially in spring before crucifer vegetable crops are planted (Talekar and Shelton, 1993; Capinera, 2001).

2.7.1.7 Damage and economic importance of Diamondback moth

Plutella xylostella is a noted defoliator of numerous cruciferous plants in many areas of the world. In some cases, this insect is considered as the most important limiting factor of successful production of cruciferous vegetables, particularly in the tropics (Lim, 1992). In Ethiopia, reported yield loss on cabbage from the pest ranges between 36.1 and 91.2 percent corresponding to 12 to 48.7 tons/ha , respectively (Ayalew, 2006). Total crop failure is common in seasons of heavy infestation in central rift valley areas (Ayalew and Ogol, 2006). Most of the chemical control in crucifer production is directed towards diamondback moth control (Carl, 1992). The global cost of controlling DBM has recently been estimated between USD 4 and 5 billion (Zalucki *et al*., 2012). Although such a large amount of money spent for the control of the pest, the level of control set the expense is low because of the physiological peculiarity of the insect to acquire resistance to insecticides very quickly, especially in tropical areas in a desperate attempt to achieve reasonable control (Talekar and Shelton, 1993). Carl (1992) indicated that over 60% of the market value of the cabbage crop is spent for the purchase of pesticides in Asian Countries without considering cost of input including pesticide application. Damage is caused by larvae feeding on leaves, or by the presence of larvae, which contaminate and lower the quality of the produce. Although they are small in size relative to other lepidopteran pests such as cabbage looper, (*Trichoplusia ni*) and imported cabbageworm, (*Pieris rapae*) densities of diamondback moth larvae can reach levels that result in total damage of leaves. For crops such as broccoli, the presence of larvae in florets can result to the total rejection of the produce (Capinera, 2001). The pest causes serious economic loss even though proper economic impact of the pest is difficult to access especially in Africa. It can destroy the entire cauliflower or cabbage crop (Gujar, 1999). This pest causes an average of 52% loss to marketable yields of cabbage (Kumar *et al*., 1983). The perceived yield loss to DBM is up to 60% on cabbage in Ghana (Chellaiah and Srinivasan, 1986; Lingappa *et al*., 2004; Obeng- Ofori *et al*., 2007; Fening *et al*., 2014).

2.7.2 Cabbage aphid, *Brevicoryne brassicae* (L.)

The cabbage aphids are small, pear- shaped, delicate insects with soft and fragile body (Kessing and Mau, 1991). It is characterized distinctively from other aphids by its short cornicles, corned- shaped or triangular cauda with seven to eight curved hairs and white waxy secretions that cover the aphids and the infested leaves (Elwakil and Mossler, 2013). The short cornicles and the waxy coating of cabbage aphids help distinguish them from other aphids that may attack the same host plant (Carter and Sorensen, 2013; Opfer and McGrath, 2013). Adult aphids may be winged or wingless and are noted to form large colonies covered with grayish waxy powdery secretions. They vary considerably in colour from light green, yellow, pink, purple to black or mixed colours. The cabbage aphid is 2.0 to 2.5 mm long and covered with a grayish waxy covering (Carter and Sorensen, 2013) and may attack the crop at any stage (Elwakil and Mossler, 2013).

2.7.2.1 Biology and ecology

Cabbage aphids have varied life cycle for which they may reproduce in two different ways (Kessing and Mau, 1991). In the warm climatic zones like Florida and Hawaii, female aphids give birth to live female nymphs without any mating or egg- laying. Here, only females are found in the colony. In temperate regions, females are induced to lay eggs after mating and this condition is temperature dependent where males are produced in response to a decrease in photoperiod (Blackman and Eastop, 1984). The overwintering stage of aphids is usually the egg stage. Generations may be overlapping to about 15 generations during the cropping season (Hines and Hutchison, 2013). In all, the duration of their life cycle ranges between 16 to 50 days depending on temperature. Higher temperatures shorten the life cycle (Kessing and Mau, 1991).

2.7.2.2 Eggs

Eggs are usually produced in the temperate climates and overwinter in plant debris near the soil surface (Hines and Hutchison, 2013) where as in warm climates only females are found in the colony, and live female nymphs are produced directly without egg laying (Kessing and Mau, 1991).

2.7.2.3 Nymphs

In warm climatic condition, eggs are usually not produced but rather the female gives birth to live female called nymphs. The nymphs are similar in appearance to the adult but slightly different in terms of their small body size, with less developed caudae and siphunculi. The nymphal period ranges from seven to ten days. Those that form wings develop and migrate to new host plants when quality of the plant reduces or when the population is large.

2.7.2.4 Adults

Aphids are pear-shaped soft bodied insects with a posterior pair of tubes called cornicles, which project backward. Aphids have piercing and sucking mouthparts. Adult cabbage aphids may be winged and wingless. Wingless adults are about 1/10 inches in length, oval in shape and grayish-green or grayish-white in colour which is attributed to their waxy covering (Natwick, 2009; Hines and Hutchison, 2013; Opfer and McGrath, 2013). The cabbage aphids have about eight dark brown or black spot at the upper part of the abdomen just below the waxy coat and the spots increase in size toward the posterior end. Unlike the wingless females, winged females are smaller in size and do not have any waxy covering (Natwick, 2009). The wings are short with prominent veins. The winged aphids have characteristic features that differentiate them from the wingless ones; having a dark brown head and thorax, dark brown antennae and a yellow abdomen with two dark spots located at the dorsal anterior segment of the abdomen which later becomes a dark band across the last abdominal segment (Kessing and Mau, 1991)

2.7.2.5 Economic importance and damage

The cabbage aphid is a destructive pest in all cabbage growing areas (Bhatia and Verma, 1994; Dattu and Dattu, 1995) causing severe loss of yield in cruciferous crops that reduce their marketability (Liu *et al*., 1994; Costello and Altieri, 1995). They cause both direct and indirect damage to cruciferous crops. With their piercing-sucking mouthparts both the adults and the nymphs cause direct damage to cabbage plant by attaching to the plant tissues and sucking juices thus, depriving the plant of nutrients (Liu *et al*., 1994). This results in curled and twisted leaves and later becomes wilted, distorted or yellowish when aphid population increases (Kessing and Mau, 1991). Aphids' feeding result in curl and spoon shaped leaves and the damage threshold rely greatly on the time of infestation (Behdad, 1982). Again aphids feeding may lead to unmarketable head, stunted growth and eventually death of the plant (Griffin and Williamson, 2012).

The indirect damage includes secretion of honeydew, contamination of harvested produce and the transmission of viral diseases (Liu *et al*., 1994). The honeydew produced by cabbage aphids tends to stimulate the growth of a black sooty mould fungus which contaminates the crop and reduces its market value (Costello and Altieri, 1995). With even low population density, aphids have economic impact on the growth and yield of the crop (Kessing and Mau, 1991).

2.7.3 Cabbage looper, *Trichoplusia ni* (Hụber)

The cabbage looper is one of the most important pests of cabbage. Young larvae initially are dusky white but become pale green as they commence feeding on foliage (Russel, 1978). Smaller larvae remain on the leaf surface while larger larvae produce larger holes throughout the leaf (Roland and Martin, 2007). In addition to feeding on the wrapper leaves, cabbage looper may bore into the developing head. Some defoliation can be tolerated before head formation but feeding damage and excrement left behind on heads makes cabbage unmarketable (Infonet-biovision, 2009; Andongma, 2010)

2.7.4 Cabbage webworm, *Hellula undalis* (F.)

The light brown caterpillars of the cabbage webworm bore into the main veins of leaves of cabbages and later into the centre of the stems where they then feed (Opfer and McGrath, 2013). This makes the pest difficult to control with pesticides (Obeng- Ofori, 1998). When webworms attack seedlings and plants, the plants do not survive (Youdeowei, 2002).. In mature cabbage plant, webworms destroy the heads completely making them unsuitable for sale (Infonet-biovision, 2009; Andongma, 2010). The main natural enemies of the webworm are predatory ants and parasitic wasps (Youdeowei, 2002).

2.7.5 Cabbage flea beetle, *Phyllotreta* spp.

These are minor pests of brassica but are so widespread and common that occasionally they cause economic damage (Obeng- Ofori, 1998). The main damage is done by the adult which feed on seedlings of brassicas (Youdeowei, 2002). They feed mainly on the cotyledons and the leaves of young plants and produce many small round holes all over the leaf surface (Obeng- Ofori, 1998). Occasionally, seedlings may be completely destroyed. The larvae generally live in the soil and feed on the roots (Andongma, 2010).

2.7.6 Variegated grasshopper, *Zonocerus variegatus* (L.)

This is a pest that has been reported to cause serious damage to cabbage plants in Ghana (Timbilla *et al.*, 2007). Surveys conducted in 2003, revealed that late instar nymphs and adults of *Z. variegatus* cause economic damage to cabbage within a fortnight of attack (Timbilla, 2006). The damage was observed to primarily occur in cabbage fields close to hatching sites of both dry and wet season populations of *Z. variegatus* and up to 26 insects could be counted per plant. Damage attributed to vegetables including cabbage by *Z. variegatus* is documented in Ghana (Timbilla, 1997).

2.8 Management of cabbage pests

Several approaches have been used to manage cabbage pests, but the most common include the following:

2.8.1 Biological control

Biological control is an alternative to chemical pest control and has the potential to provide resource - poor farmers' low cost natural pest control, to reduce the dependency on pesticides (Youdeowei, 2002). Biological control can be very effective if control agents are available. There are over 90 parasitoid species recorded attacking the DBM larvae and pupae in integrated pest management programmes for commercial cabbage production (Furlong *et al*., 2004; Jankowska and Wiech, 2006).

Parasitoids attack the pest in different developmental stages. It is relevant to determine the association between biological control agents and specific stages of the pests to improve biological control strategies (Furlong *et al*., 2004). A number of natural enemies attack insect pests of cabbage. In Ghana, the most important parasitoids include *Cotesia plutella* (Kurdjumov) (Hymenoptera: Braconidae) and *Hockeria* sp. (Hymenoptera: Chalcididae) which attack the DBM, *Charops flavipes* (Brullé) (Hymenoptera: Ichneumonoidea) which attack *Trichoplusia nii*, and the *Chelonus* sp. and *Blepharella* sp. attack *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) (Youdeowei, 2002). Predators such as brown lacewings, *Micromus tasmaniae* (Walker) (Neuroptera: Hemerobiidae), several predacious bugs like *Nabis tasmanicus* (Strommer), leafhoppers and some dermapterans feed on the eggs, larvae and pupae of insects and further contribute to mortality (Obeng-Ofori, 1998). Nuclear polyhedrosis viruses that occur naturally in the field and *Bacillus thuriengiensis* (Bt) are also effective against lepidopteran insect pests that attack cabbage (Roland and Martin, 2007).

Biological control approach has considerable promise, although the widespread and indiscriminate use of insecticide has frustrated efforts and delayed the establishment of parasitoids and their beneficial effects (Talekar and Shelton, 1993). Even though biological control has not been greatly exploited in Ghana, few economic impact studies have revealed high benefits of biological control in the control of the cassava and mango mealy bugs (Alene *et al*., 2005).

2.8.2 Host plant resistance

This is a technology that represents an attractive control tool to farmers, particularly those in the urban areas in Ghana (Horna *et al*., 2007). Crucifer crops differ somewhat in their susceptibility to attack by insect pests such as diamondback moth. Mustard, turnip, and kohlrabi are among the more resistant crucifers (Stoner, 1990). Several studies have surveyed existing germplasm for plant resistance to Lepidoptera including the DBM on crucifers (Shelton *et al*., 1988; Dickson *et al*., 1990; Talekar and Shelton, 1993).

The resistance is chemically based and elicits antibiosis in the larvae, causing levels of mortality (Eigenbrode and Shelton, 1990). Recent studies indicated that application of s-ethyldipropylthiocarbamate to normal bloom cabbage changed the leaf surface waxes similar to those of the genetic glossy type and thereby became resistant to the DBM larvae (Eigenbrode and Shelton, 1992a; Eigenbrode and Shelton, 1992b). In Europe and India, rape and brussel sprouts varieties were identified to be resistant to cabbage aphid (Russel, 1978; Pakhraj *et al*., 2005). Some cultivars of crucifera have also shown to be resistant to cabbage aphid infestation than others (Singh and Ellis, 1993; Ellis *et al*., 1998)

2.8.3 Mating disruption using sex pheromones

A number of sex pheromones are available for the management of lepidopteran pests of vegetables, including cabbage (Badenez-perez *et al.*, 2004). The use of DBM pheromones has been exploited particularly when used in combination with augmentation or conservation of natural enemies. Furthermore, sex pheromones and larval frass volatiles from the diamondback moth, as well as volatile compounds from cabbage, may be used by these natural enemies to locate their diamondback moth host (Reddy, 2002).

Pheromone has been used to monitor the DBM populations in the field (Koshihara, 1988). In Japan, scientists have succeeded in achieving mating disruption in cabbages fields using high concentrations of pheromone (Nemoto *et al*., 1992; Ohbayashi *et al*., 1992). A 1: 1 mixture of (Z) - 11-16: Ald and (Z) - 11-16: OAC, known as KONAGA- CON, is now commercialized in Japan and collaborative multi- location trials have shown promising results (Ohbayashi *et al*., 1992). Gabrys *et al*., 1997 indicated that the sex pheromone (4a*S*,7*S*, 7a*R*) - nepetalactone proved to be effective in a laboratory bioassay by increasing the catches of males of *B. brassicae* when it was released from glass vials placed above water traps in crops of autumn brassicas. In addition, larger population of parasitoids of *B. brassicae*, *Diaretiella rapae*, and the more general aphid parasitoid, *Praon volucre*, were caught in pheromone traps (Gabrys *et al*., 1997).

2.8.4 Insecticides

2.8.4.1 Insect growth regulators (IGR's)

Insect growth regulators (IGRs) slowly kill the insects over a period of few days by disrupting the normal growth and development of immature insects (Ohbayashi *et al*., 1992). IGRs insecticides are comparatively safer to beneficial insects and environment, and are compatible for use in an integrated pest management system. Novaluron for example acts as an insecticide mainly by ingestion but has some contact activity (Odhiambo, 2005). Examples of brand names of some IGRs include Azatin (Azadirachtin 3%), Estar II (S-Kinoprene) and Preclude (fenoxycarb) (Obeng- Ofori, 1998). They have been used to control many insects. An example of IGRs used in Ghana is Rimon® (Odhiambo, 2005). Insect growth regulators and pathogens offer a promising control measure as a viable alternative to broad- spectrum insecticides, which often disrupt the control exerted by natural enemies (Kobayashi *et al*., 1992).

2.8.4.2 Microbial/ biopesticides

Biopesticides or microbial controls consist of *Bacillus thuringiensis* (Bt), insect - consuming fungi such as *Beauveria bassiana, Metarhizium anisopliae*, and viruses such as Baculoviruses (Furlong *et al*., 2004). Bt is a naturally occurring bacterium that produces a toxin that causes paralysis of a caterpillar's digestive tract (Guerena, 2006). A caterpillar may continue to live for some hours after ingestion, but will not continue to feed. Bt strains are available in a number of commercial products, under various trade names. Bt degrades rapidly in sunlight and requires careful timing or repeated applications (Thompson and Hutchins, 1999; Guerena, 2006). Bt must be ingested in sufficient amounts on the caterpillar to be effective. Consequently, growers must understand the feeding habits of the pests, so that proper formulations are used and timing of applications is optimal (Botwe *et al*., 2012). Caterpillars in their early stages of development (first and second instars) are more susceptible to this toxin, whereas, older and bigger worms are harder to kill (Guerena, 2006).

Spinosad is one of such new chemicals which are derived from fermentation broth of soil actinomycetes, *Saccharopolyspora spinosa*, containing a naturally occurring mixture of spinosyn A and spinosyn D. Spinosad have rapid contact and ingestion activity in insects, causing excitation of the nervous system, leading to cessation of feeding and paralysis (Thompson and Hutchins, 1999). It is a safer and biodegradable insecticide and has a known insecticidal property that could be feasible and effective for insect pest management (Ghosh *et al*., 2010). Spinosad provides effective control of Lepidopteran, Thysanopteran pests and some Coleopteran, Homopteran, Hymenopteran and Orthopteran species (Cherry *et al*., 2004). There is no reported phytotoxic activity of spinosad based products. Degradation of spinosad in the environment occurs mainly by photo - degradation and microbial degradation (Isman, 2008). Spinosad has relatively low toxicity to mammals and birds and exhibits wide margin of safety to many beneficial insects (Thompson and Hutchins, 1999).

2.8.4.3 Synthetic insecticides

Three different classes of insecticides have been used to manage insect pests of cabbage in Ghana. These include organophosphates, carbamates and pyrethroids (Ntow, *et al*., 2006; Andongma, 2010). Insecticides such as lambda - cyhalothrin, deltamethrin, cypermethrin, dimethoate have been widely used in Ghana for the control of major insect pests of cabbage (Table 2) (Odhiambo, 2005; Amoako 2010).

Table 2: Pesticides used to control insect pests on cabbage between 2004 –2008 in Ghana.

Common Name	Active Ingredients	Type	Pre- harvest application intervals
Golan S L	Acetamiprid	Neonicotinoid	7 days
Deltapaz 2.5 EC	Deltamethrin	Pyrethroid	7 days
Cypercal 50 EC	Cypermethrin	Pyrethroid	7 days
Karate 5 EC	Lambda cyhalothrin	Pyrethroid	7 days
Pyrical 480 EC	Chloropyrifos Ethyl	Organophosphate	7 days
Orthene 750 sp	Acephate	Organophosphate	4 days
Pawa 2.5 EC	Lambda cyhalothrin	Pyrethroid	4 days
Cymethoate	Cymethoate	Organophosphate	7 days
Dimethoate	Dimethoate	Organophosphate	15 days
Sumithion	Fenitrothion	Organophosphate	14 days
Dursban 4 E	Chlopyrifos	Organophosphate	15 days
Thionex 35 EC	Endosulphan	Organochlorine	14 days
Cymthox	Fenvalerate	Pyrethroid	7 days
Thiodan	Endosulphan	Organochlorine	14 days
Mektin 1.5 EC	Abamectin	Bio- insecticide	3 days
Confidor 200sl	Imidacloprid	Neonicotinoids	7 days
Diazol 50 EC	Diazion	Organophosphate	7 days
Wrecko 2.5 EC	Lambda cyhalothrin	Pyrethroid	15 days
Endocel	Endosulphan	Organochlorine	15 days
Lambda Super 2.5 EC	Lambda cyhalothrin	Pyrethroid	3 days
Attack	Emamectin benzoate	Bio- insecticide	7 days
Kombat 2.5 EC	Lambda cyhalothrin	Pyrethroid	3 days
Actellic	Pyrimiphosmethyl	Pyrethroid	7 days
Polythrine C	Cypermethrin + profenetos	Pyrethroid	7 days
Rimon 10 EC	Novaluron	IGRs	7 days
Cocostar	Bifenthrin + pyrimiphosmethyl	Pyrethroid	7 days
Akate Master	Bifenthrin	Pyrethroid	7 days

Source: Amoako, 2010.

2.8.4.4 Sunhalothrin® (Lambda cyhalothrin 2.5% EC)

Sunhalothrin® is a broad spectrum insecticide which has lambda cyhalothrin as its active ingredient (Odhiambo, 2005; Andongma, 2010). It works by opening the sodium channels in the neuronal membrane. It affects both the central and peripheral nervous systems of the insect. It initially stimulates nerves cells to produce repetitive discharge and eventually causes paralysis (Odhiambo, 2005). Such effects are caused by their effects on the sodium channels (Ware and Whitacre, 2004). Lambda cyhalothrin is a synthetic pyrethroid insecticide used for the control of a wide range of pests in a variety of applications (Amoako, 2010). Lambda cyhalothrin 2.5EC is highly active against a wide range of species of Lepidoptera, Hemiptera, Diptera and Coleoptera (WHO, 1990). Pests controlled include caterpillars, aphids, grasshoppers, mealybugs, beetles, etc. (Amoako, 2010). Apart from agricultural use, lambda cyhalothrin also has public and animal health applications in which it effectively controls a broad spectrum of insects including cockroaches, flies, mosquitoes and ticks (Andongma, 2010). It is active as residual spray or inert spray used on surfaces (WHO, 1957). Farmers in the Accra Metropolis reported that lambda cyhalothrin was very effective in the control of insect pest complex of cabbage (Odiambo, 2005.)

2.8.5 Cultural practices

Cultural methods of controlling pests are very useful and effective but have not received the needed attention and support (Stoll, 2003). This is considered important to suppress pest populations in IPM programmes (Brader, 1979). Some of the classical control methods that have been tried with some success are intercropping, sprinkler irrigation, trap cropping, crop rotation and clean cultivation (Talekar and Shelton, 1993). Low DBM populations have been reported in intercropped cabbage fields (Meyer, 2007). Asare- Bediako *et al.*, (2010) also reported that intercropping cabbage with onion, tomatoes and pepper in Ghana was as effective as spraying with chlopyrifos. Cabbage - tomato intercropping is reported to reduce infestation of DBM in the cabbage (Bijlmaker, 2005). The odour from the tomato intercrop repels the DBM (Minja *et al*., 2003; Stoll, 2003) or has an oviposition deterring effect on DBM (Endersby and Morgan, 1991).

Planting of trap crops is one of the cultural methods used for pest management (Metcalf, 1975; Talekar and Shelton, 1993). Indian mustard, Chinese cabbage and radish are good trap crops for controlling cabbage webworm, flea hopper and mustard aphid when planted at every 15 rows of cabbage (Infonet-biovision, 2009). Hokkanen (1991) suggests that at least 35-40 important pest species could likely be controlled with some form of trap cropping, and yet only a handful of trap crop systems are used regularly in commercial agriculture. Exploring the potential of new trap crop systems and developing methods that are acceptable to farmers is an important strategy for increasing the economic and environmental sustainability of farms (Talekar and Shelton, 1993).

2.9 Use of botanicals and their importance in pest management

Many African countries are rich in plant products that are traditionally used by the rural inhabitants for medicinal purposes and in some instances as preparations for insect control (Amoabeng *et al*., 2013). Certain plant families, particularly Meliaceae, Rutaceae, Asteraceae, Labiatae, Piperaceae and Annonaceae have been viewed as exceptionally promising sources of plant-based insecticides (Jacobson, 1989; Isman, 1995). The use of conventional insecticides has raised some concerns, about their threats to the environment and development of insecticide resistance in insects (Champ and Cribb, 1985; Halliday *et al*., 1988; Barbara, 1993). There is an imperative need for the development of safer, effective and efficient alternative crop protectants such as botanical insecticides which are biodegradable pesticides with greater selectivity (Fening *et al*., 2013; Amoabeng *et al*., 2013). Currently, pest control mechanism is based largely on imported synthetic insecticides, which are frequently priced beyond easy reach of small farmers, who constitute a very large proportion of the farming population (Amoabeng *et al*., 2013).

The role of botanical insecticides in insect pest management and crop protection in Africa is of much importance due to continual use of effective but ‘toxic’ commercial pesticides (Amoabeng *et al*., 2013). However, the regulatory environment and public health needs have created opportunities for the use of safer botanicals, since human and animal health is now paramount (Fening *et al*., 2013; Amoabeng *et al*., 2013). Botanicals have also found its use in organic food production, both in the field and in controlled environments for export to developed countries where strict pesticide levels are strictly monitored in horticultural products before export (Heyde *et al*., 1984; Kareru *et al*., 2008). In addition the greatest benefits from botanicals might be achieved in developing countries, where human pesticide poisonings are most prevalent (Kareru *et al*., 2013).

In Africa, extracts of locally available plants have been traditionally used as crop protectants, when used alone or in mixtures (Table 3). In fact indigenous knowledge and traditional practice have made valuable contributions to domestic food production in countries where strict enforcement of pesticide regulations is not applied (Kareru *et al*., 2013).

Table 3: Some plants traditionally used to control crop pests and diseases.

Plant	Pests/ Diseases
Neem tree	Armyworms, Stem borers, Bollworms, Leaf miners, Diamondback moth, Caterpillars, Storage pests (moth), Aphids, Whiteflies, Leaf hoppers, Psyllids, Scales, Maize tassel, Beetle, Thrips, Weevils and Flour beetle
Garlic/Onions	Caterpillars, Cabbage worms, Aphids
Stinging nettle	Caterpillars
Tithonia diversifolia	Caterpillars, aphids
Spider weed	Aphids
Aloe spp.	Ash Storage moths, Storage beetles
Hot pepper	Diamondback moth, Stem borers, Bollworms, Cutworms, weevils, Aphids, Beetles
Tobacco	Stem borers, Cutworms, Caterpillars, Grain weevils
Pyrethrum + Mexican marigold	Caterpillars, Aphids, bugs, Beetles
Chilies + Mexican marigold	Armyworms, Stem borers, Bollworms, Cutworms, Leaf miner, Diamondback moth, caterpillars, Aphids
Garlic, *Allium sativum* + hot pepper, *Capsicum frutescens*	DBM, Aphids, cabbage webworm
goat weed (*Ageratum conyzoides*) + Siam weed (*Chromolaena odorata*)+ Cinderella weed (*Synedrella nodiflora*)+ chili pepper(*Capsicum frutescens*)+ tobacco (*Nicotiana tabacum*)+ Cassia (*Cassia sophera)*+ physic nut (*Jatropha curcas*)+ castor oil plant (*Ricinus communis*) and basil (*Ocimum gratissimum*)	DBM, Aphids, cabbage webworm and other insect pests of cabbage

Source: Mureithi, 2008; Amoabeng *et al*., 2013; Fening *et al*., 2013.

Studies in some Africa countries suggest that extracts of locally available plants can be effective as crop protectants (Isman, 2008). Among the botanicals used are natural pyrethrins, the neem extract, *Azadirachta indica* (A. Juss), *Khaya senegalensis* against cotton bollworm (in Benin) and extracts from marigold against bruchid beetles from cowpeas in storage in Uganda (Kawuki *et al*., 2005). Shelton and Zhao, (2004) documented a survey of botanical extracts used as insecticides among farmers within the Victoria Basin. The study demonstrated that most subsistence farmers use botanical pesticides for pest management in their farms. Among the plants used were *Capsicum frutescens*, *Tagetes* spp, *Nicotiana tabacum*, *Cypressus* spp., *Tephrosia vogelii*, *Azadirachta indica*, *Musa* spp., *Eucalyptus* spp. and *Carica papaya*.

In Benin, West Africa, the bush mint, *Hyptis suaveolens* extract has been used for the control of pink stalk borer, *Sesamia calamistis* H. (Lepidoptera: Noctuidae) on maize. Also, botanical insecticides have been tried for the protection of cowpeas in Ghana (Abatania *et al*., 2012). Ogunsina *et al*., (2010) investigated plant extracts from *Lantana camara* (Verbenaceae) and African nutmeg (*Monodora myristica* (Gaerth) against bean weevil *Callosobruchus maculatus* (F.) and maize weevil, *Sitophilus zeamais* Motsch. The overall results showed that bean weevil was much more susceptible to all the extracts than maize weevil.

In Ghana, several botanicals such as *Azadirachta indica, Ocimum Americana, Capsicum frutescens, Pleiocapa mutica, Cassia sophera, Pterocarpus erinaceus, Chamaecrista nigricens, Securidaca longepedunculata, Citrus sinensis, Combretum sp.,Synedrella nodiflora, Cymbopogon schoenanthus, Chromolaena odorata, Khaya senegalensis, Vitellaria paradoxa, Lippia multiflora, Mitragyna inermis.*etc have been used to protect foodstuffs such as vegetables and stored grains against insect pest infestations (Obeng-Ofori and Ankrah, 2002).

Botanical insecticides contain compounds with properties that repel, deter or disrupt the growth, feeding or reproductive activities of insect pest on crops (Oparaeke, 2005; Ahmed *et al*., 2009; Degri *et al*., 2012; Degri *et al*., 2013). Botanical insecticides tend to have broad spectrum activity, relatively specific in their mode of action, and easy to process and use at farm levels. They are also safe for higher animals and the environment (Annonymous, 1991). Botanical insecticides can often be easily produced by farmers and small-scale industries; the indigenous plant materials are cheaper and hazard free in comparison to chemical insecticides (Saxena *et al*., 1980). Plants are rich sources of natural substances that can be utilized in the development of environmentally safe methods for insect control (Sadek, 2003). Crude plant extracts often consist of complex mixtures of active compounds, they may show greater overall bioactivity compared to the individual constituents (Berenbaum *et al*., 1991; Chen *et al*., 1995). The deleterious effects of crude plant extracts on insects were seen in several ways, including toxicity (Hiremath *et al*., 1997) and feeding inhibition (Wheeler and Isman, 2001).

2.10 Common plants used as botanicals

2.10.1 Siam weed, *Chromolaena odorata* (Asteraceae)

Chromolaena odorata is a Neotropical plant (Plate 3). According to Voigt (1845), *C. odorata* was introduced to Calcutta botanical gardens, India in 1845. From its original point of introduction as an ornamental, it spread throughout Southeastern Asia into parts of Oceania and into West and Central Africa (Gautier, 1992). It was accidentally introduced to Nigeria in 1937 (Munniapan and Marutani, 1988). Hall *et al*., (1972) reported that the weed was first discovered in Ghana in 1969 and by 1991 it had colonized about 67% of the total land area of the country (Braimah and Timbilla, 1991; Timbilla and Braimah, 1996). *Chromolaena odorata* contains diverse range of secondary chemicals including flavonoids, terpenoids and alkanoids (Talapatra *et al*., 1974; Biller *et al*., 1994). In China, analysis of the volatile oil from *C. odorata* identified 33 components with terpenoid compounds being the majority (Boeke *et al*., 2004). The main terpenoid compounds are trans-caryophyllene (16.22%), A-cardinene (15.53%), a-capaene (11.32%), caryophyllene oxide (9.42%), germacrene-D (4.86%) and humulene (4.23%). Similar work in Thailand identified 22 constituents (Nisit *et al*., 2006). Also, phenolic acids (protocatechuic, p-hydroxybenzoic, p-coumaric, ferulic and vanillic acids) and complex mixtures of lipophilic flavonoid aglycones (flavanones, flavonols, flavones and chalcones) were found in the crude ethanol extracts of the leaves of *Chromolaena odorata* (Toan-Thang *et al*., 2001). Nisit *et al*., (2006) also investigated the chemical constituents of the leaf extract of *C. odorata* after separation and purification. Six flavanoids were obtained including 3,5,4`-trihydroxy -7-methoxyflavanone; 5,7,3 trihydroxy -5- methoxyflavanone and 3,5,7- tridroxy-methoxyflavanon.

Biller *et al*., (1994) reported that *C. odorata* contains a mixture of pyrrolizidine alkaloids (PAs) with the major components being rinderine and intermedine, as well as other PAs in smaller quantities all occurring exclusively as N-Oxides with the highest concentration occurring in the roots and in the flowers but absent in the leaves.

Caryophyllene and germacrene-D which have been reported to be major constituents in *Lantana camara* leaf has been established to possess insecticidal activity against *Dactynotus carthami* (Patil *et al*., 1997), repellent towards bees, mosquitoes and cattle flies

(Attri and Singh, 1978) and ovipositional effect against *Callosobruchus maculatus.* Coumarine a constituent of *C. odorata* is also well known to possess insecticidal properties.

Plate 3: Siam weed plant (*Chromolaena odorata*).

2.11 Neem tree (*Azadirachta indica* A. Juss)

The neem tree, *Azadirachta indica* A. Juss belongs to the family Meliaceae (Plate 4). It is a tropical evergreen tree related to mahogany (Tomar and Singh, 2008). The tribe Melieae consists of two genera *Azadirachta* and *Melia* (Rimpi *et al*., 2010).This tree is native to the coastal fringe forests of the drier tropical region of East India, Sri Lanka and Burma (Massaguni and Latip, 2012). It is currently widespread in Pakistan, Myanmar, Thailand, Malaysia and Indonesia (Tomar and Singh, 2008). The neem tree is undemanding and grows well on moist, dry, stony, clayey or shallow soils. Therefore, it is able to grow almost anywhere in the lowland of the tropics (Massaguni and Latip, 2012). However, it generally performs best in areas with annual rainfall of 400-1,200 mm (Tomar and Singh, 2008).

Azadirachtin ($C_{35}H_{44}O_{16}$) is a tetranortriterpenoids (limonoids) which is extracted from *Azadirachta* plant species. This compound in neem has insecticidal properties such as antifeedant, repellence, oviposition deterrent, molting inhibition and a growth retardant for different insects' species and arthropods (Rimpi *et al*., 2010). Although, every part of the neem tree contains azadirachtin substance, most previous research have shown that the seed kernels contains higher amount of azadirachtin (Boeke *et al*., 2004). Azadirachtin in the neem seed kernel is about 0.1 - 0.5% by weight of the seed. Besides the azadirachtin, neem also contains more than 20 compounds that are responsible for the characteristics smell of crushed seeds and neem oil (Massaguni and Latip, 2012).

Plate 4: Fresh neem seeds.

2.11.1 Importance of neem as botanicals

Extracts of neem are often used to protect stored grains against insects by mixing the grains and the extract. Boeke *et al*., (2004) found that the leaf powder, the seed oil and all kinds of extracts do indeed have a negative effect on seed-eating insects. However, if these plant parts are used to treat stored seeds against insects, the mammalian consumers of these seeds especially human beings should not be affected by residues of this treatment (Obeng- Ofori and Ankrah, 2002). The reason is that neem is reported to be safe for humans and the environment as it has not been found to possess toxic compound. Yu (2008) found that neem products are considered safe because the oral LD50 in rats is >5000 mg/kg making it essentially non- toxic to mammals. The neem leaves and other plant parts are valued for their therapeutic and medicinal properties and have extensively been used to treat many ailments in India (Obeng- Ofori and Ankrah, 2002). Many disorders like inflammation, infections, fever, skin diseases, dental disorders and others have been treated with different parts of the neem tree (Girish and Shankara, 2008). In addition, neem also exhibits a wide range of pharmacological activities such as blood sugar lowering properties, anti-inflammatory, antihyperglycaemic, antiulcer, antimalarial, antifungal, antibacterial, antiviral, antioxidant, antimutagenic, anticarcinogenic and immunomodulatory (Boeke *et al*., 2004).

Among 2,400 plants investigated, neem was rated on top in terms of its pesticidal properties and was regarded as the most reliable source of eco-friendly biopesticide (Obeng- Ofori and Ankrah, 2002). The preparation of neem is cheap and highly effective and thus constitute an important source of pesticide for economically poor farmers (Massaguni and Latip, 2012; Obeng- Ofori and Ankrah, 2002).

The increasing amount of research on insect-plant chemical interactions has provided the potential of utilizing botanicals insecticides in the form of secondary plant metabolites or allelochemicals (Senthil-Nathan *et* al., 2009). These naturally occurring biocidal agents have been shown to be selective, readily biodegradable and safe to human (Obeng- Ofori and Ankrah, 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study location

The research was conducted at the University of Ghana's Forest and Horticultural Crops Research Centre (FOHCREC), Kade, in the Kwaebibirem district of the Eastern Region. The Centre is located approximately 120 km North- west of Accra (6^o 09N, 0^o 55W) (Gray, 1987) and approximately 135.9 m above sea level. It lies within the moist deciduous forest zone of Ghana and within the wet semi- equatorial climatic region (Ofosu- Budu, 2003). The climatic condition is representative of a tropical humid forest zone (Dickson and Benneh, 1995; Ofosu- Budu, 2003).

The area has an annual bimodal rainfall amount ranging between 1200- 1300 mm, and temperature range of 25- 34^{o}C and monthly actual evapotranspiration of 1200mm/ year (Christiansen and Awadzi, 2000; Ofosu- Budu, 2003). The relative humidity ranged between 60 and 80% throughout the year (Dickson and Benneh, 1995). The Centre has been involved in the promotion of forest and horticultural crops production and protection since its establishment in 1957 (Ofosu- Budu, 2003).

3.2 Preparation of treatments

The *C. odorata* crude leaf extracts were prepared along with the neem seed extract as standard botanical. The reference conventional insecticide, sunhalothrin and the control, tap water treatments were also prepared prior to application of various treatments.

3.2.1 Preparation of *Chromolaena odorata* leaf extracts

Fresh leaves of *C. odorata* were cut from a field around the Centre and two other suburbs (Nkwantanang and Okumaning) situated four kilometers from the Centre. The leaf samples taken from the different localities were mixed and washed with water to remove sand, dust and chemical contaminants. The leaves were shade-dried for about an hour on a clean concrete platform to drain off excess water and then ground into coarse powder using wooden pestle and mortar. To prepare 10g/L of the extract, 10g of the powder was weighed and then soaked in plastic bucket containing 1 litre of warm water. The resulting solution was then stirred continuously for 10 minutes and left to stand overnight. Filtration of the leaf extract was done shortly before application using muslin cloth. The stickiness and adherence of the plant extract was enhanced by the addition of about three drops each of natural vegetable oil (0.15 ml per litre) and local soap (*alata samina*) solution (3% w/v) as surfactant (Fening, *et al*., 2014). Similar procedures were used to prepare 20 and 30g/ L of the extract

3.2.2 Preparation of neem seed extracts

Fresh neem seeds were collected along Winneba- Apam road and dried in the sun for a week. Before the preparation of the extract, the neem seeds were air-dried at room temperature, and the shells removed from nuts. The nuts were pounded using a pestle and mortar to obtain coarse powder which was used for the treatment solution. Crude plant extracts were prepared by adding 1 litre of distilled water to 50 g weighed plant material to get desired dose. The solution was left overnight and filtered through fine linen material. A few drops of local soap solution (Alata samina- 3% w/v) were added to the final extract to act as a surfactant. The solutions were independently used for the field experiments. The neem is being used in this study as a standard botanical to compare with the performance of *Chromolaena odorata*, which is the target botanical.

3.3 Field experiment

3.3.1 Nursery establishment

Cabbage seeds (cv. oxylus) were obtained from AGRIMAT Limited shop in Accra. The seeds were nursed in rows in seed trays and seed boxes raised 1 m above the ground. The nursery media were made up of sandy loam mixed with carbonated rice husks in a ratio 2: 1. Watering was done manually with watering can. Fertilizer (NPK) was applied to the soil media as starter solution at a rate of 20g per litre of water. Fungicides (Mancozeb- 20g/L) were also sprayed on the seedlings to prevent fungal infection during the early stages of growth.

3.3.2 Land Preparation, field layout and transplanting

The land was manually cleared and later sprayed with herbicide (2, 4- D) before cabbage seedlings were transplanted onto raised beds. The field layout was done, with each plot or bed measuring 1.5 m wide x 2.5 m long. A 2 m wide unplanted alley was allowed between and within each plot or bed to avoid spray drift. The experimental field, which measures 19 m x 11.5 m, were pegged and labeled with three replications, prior to planting. Cabbage seedlings (cv. oxylus) were transplanted at the 4-5 true leaf stages (about 30 days after sowing) in a spacing of 0.5 x 0.5 m with each plot containing 24 plants. Replacement and refilling of weak, diseased or infested seedlings were carried out 2 weeks after transplanting. A starter solution of N,P,K fertilizer, 20g/L was diluted in water and applied to each plot. Standard cultural and agronomic practices such as weed control, watering and earthing-up of soil to improve aeration were employed during the growing period.

3.4 Experimental design, treatments and agronomic practices

The design was a randomized complete block consisting of six treatments which were replicated three times.

The treatments were:

T1: Application of 10 g/L crude extract of *C. odorata* leaves (150g/ 15litres),

T2: Application of 20 g/L crude extract of *C. odorata* leaves (300g/ 15litres),

T3: Application of 30 g/L crude extract of *C. odorata* leaves (450g/ 15litres),

T4: Application of 50 g/L Neem seed extract (750g/ 15litres),

T5: Application of Sunhalothrin® (Lambda cyhalothrin)- 2.5ml/ L (37.5ml/ 15litres),

T6: Tap water/ Control.

A 15 litre capacity knapsack sprayer was used to apply each of the treatments at recommended doses. Application of treatments started two weeks after transplanting of seedlings. Watering was carried out daily to avoid the withering and dying of seedlings especially at the early stages of transplanting. Weeds were manually controlled with a hoe or cutlass at two weekly intervals.

3.5 Data collection, yield and damage assessment

3.5.1 Data collection

Data collection started 14 weeks after transplanting and it was carried out weekly for all the growing seasons. Data on insect pest population including DBM, aphids, grasshoppers and other pests and natural enemies were counted and recorded from the middle rows, with the border plants excluded, which had an average of eight (8) cabbage plants per plot. Cabbage aphids were much more numerous and difficult to count without disruption, so they were scored as follows: 0 = absent, 1 = a few scattered individuals, 2 = a few isolated small colonies, 3 = several small isolated colonies, 4 = large isolated colonies and 5 =large continuous colonies (Afun *et al*., 1991; Fening *et al*., 2013).

The assessment of the numbers of various insect pest species was done by carefully examining eight (8) cabbage plants selected; leaf by leaf and turning of leaves as well to collect any insects from the under-surface of the leaves (Fening *et al*., 2014). Observations were conducted in the first week after transplanting before the application of treatments for both seasons, after which data samplings were taken 3 days after each treatment application. Data collections were done between 06:00 and 08:00 GMT.

3.5.2 Multiple head formation and head damage assessment

At harvest eight innermost cabbage plants were selected from each treatments plot for assessment. Head damage index were rated using the modified scale of Dreyer, 1987. Table 4 below shows the description of the scale.

Table 4: Modified scale of Dreyer (1987) used for damage scoring on cabbage varieties at Kabete field station, Togo.

Score	**Description**
1	No damage, or few isolated small holes in the outer or lower leaves
2	Many holes but damage limited to outer or lower leaves
3	Considerable damage of the outer or lower leaves and slight damage on the cabbage head, head marketable with minor leaf removal of outer head leaves
4	Outer or lower leaves completely destroyed, moderate attack of inner leaves, head marketable after considerable removal of outer head leaves
5	Severe attack on the head (head unmarketable)

Cabbages with multiple or split heads were also counted. The percentage multiple heads were expressed as:

$$= \frac{\text{Number of multiple heads}}{\text{Total number of selected plants}} \times 100\%$$

The marketable and un-marketable heads were sorted out in percentages to determine the consumers' acceptability. Percent data were arcsine square root transformed before analysis using ANOVA.

3.5.3 Yield assessment

At harvest, cabbage heads were used for yield assessment. This was done by harvesting heads from inner rows of each plot and cleaning them from traces of soil and then weighing the individual heads on a digital weighing scale at the field. The head weights were recorded, respectively for each of the eight plants on each plot.

3.6 Cost- benefit Assessment

3.6.1 Costs of treatments

The costs of treatments were recorded in the two field experiments conducted during the major and minor rainy seasons of 2014. Treatments of crude water extracts of readily available insecticidal plants (botanicals) were compared with the synthetic insecticide, lambda cyhalothrin (Sunhalothrin®) and tap water or control. The botanical (siam weed, *C. odorata*) used in this study were obtained in the surrounding without purchase but neem seed, *A. indica* were obtained at amount of GH¢ 20.00 per bag. The associated costs were only for labour in the collection, preparation and application of treatment dose. For the synthetic insecticide, the cost of the product was added to the labour cost of spraying. Labour cost was based on the existing wage for an unskilled labour at the locality at the time of study. This was GH¢50.00 per man day. For the purposes of the economic analyses, values were calculated on a per hectare basis.

In the major season, a man - day of labour was used for collection and preparation of the botanicals and ensuring that the botanical (siam weed, *C. odorata*) treatment was prepared fresh before use. Neem extract preparation had a total of 2 man days of labour in the collection and preparation. A bag of neem seeds cost was GH¢20.00 and 3bags were used. There were six sprayings in the major rainy season which costed GH¢50.00/ spray. Sunhalothrin® was costed at GH¢150.00/ha for six applications at GH¢50.00.

In the minor season, a man day was used for the collection and preparation of each botanical (siam weed, *C. odorata*) whilst 2 man days were used for neem extract preparation. Cost of Sunhalothrin® was GH¢150.00/ha. There were seven sprayings in the minor rainy season which costed GH¢50.00/ spray. The externalities such as potential impacts on the environment, natural enemies, and farm worker and consumer safety associated with each of the treatments were not considered in the analyses (Amoabeng *et al*., 2014).

3.6.2 Assessment of economic benefits

At harvest, plot yields were weighed and recorded. Cabbage heads from each plot were sorted into marketable and unmarketable based on insect damage and weight of cabbage head. Individual cabbage head was weighed and sold at the prevailing price on the local market. Marketable heads were sold at GH¢1.50/ kg (1,500/ ton) and GH¢2.50/ kg (2,500/ ton) for the major and minor seasons, respectively, while unmarketable heads at GH¢0.50/ kg (500/ ton) and GH¢1.00/ kg (1,000/ ton) for both seasons, respectively. Income was converted to a per hectare basis by extrapolating the plant population of plots based on a plant spacing of 0.5 m x 0.5 m taking into account unplanted alleys to facilitate movement within the field. This resulted in a total plant population of 64,000 per hectare, following the procedures used by Amoabeng *et al*., 2014.

3.7 Data Analyses

3.7.1 Field experiments

Mean weekly count data for *P. xylostella* and other pests and natural enemies and the score data for *B. brassicae* were computed. All data were subjected to analysis of variance (ANOVA) using the JMP 10 statistical package. The number of insect counts was transformed using square root transformation. Treatment means separation was by the Tukey- Kramer's HSD test and the probability of treatment means being significantly different was set at $P < 0.05$.

3.7.2 Economic analysis

Mean head weight per plant, percentage of marketable (undamaged) heads and unmarketable (damaged) head yield per hectare were subjected to analysis of variance using JMP. Percentage data were arcsine square root transformed prior to the statistical analysis. On achieving significant differences ($P < 0.05$) mean separation was performed using Tukey- Kramer's HSD test.

***Formulae for calculating each section in* Table 11 and 12**

1) Marketable Yield (ton/ ha) = Percent no. of marketable head per treatment **x** average head weight per plant

2) Unmarketable Yield (ton/ ha) = Percent no. of unmarketable head per treatment **x** average head weight per plant

3) a. Cost of botanical treatments (GH¢/ Ha) = labour cost of collection and preparation **+** labour cost for spraying per Ha

   b. Cost for synthetic insecticide (GH¢/ Ha) = Cost of product **+** labour cost for spraying per Ha

4) Income from marketable head (GH¢/ Ha) = Marketable head yield **x** Selling price per tonne

5) Income from unmarketable head (GH¢/ Ha) = Unmarketable head yield **x** Selling price per tonne

6) Total income (GH¢/ Ha) = Income from marketable head (GH¢/ Ha) **+** Income from unmarketable head (GH¢/ Ha)

7) Net benefit (GH¢/ Ha) = Total income (GH¢/ Ha) – Cost of treatments (GH¢/ Ha)

8) Benefit over control = Income from sprayed treatments (GH¢/ Ha) – Income of the control treatment (GH¢/Ha)

9) Cost benefit ratio = $\dfrac{\text{Net income of sprayed treatment – Income of control treatment}}{\text{Total cost of sprayed treatment}}$

CHAPTER FOUR

4.0 RESULTS

4.1 Insect fauna found on cabbage field during the growing seasons

The cabbage plants attracted a number of insect pests at different stages of the plant growth due to their nutritive and luxuriant nature. The most abundant insect pests recorded during the major rainy season were the cabbage aphids and the cabbage webworms, whiles those in the minor rainy season were the variegated grasshoppers, the aphids and the diamondback moth (Table 5).

Table 5: Insect pests of cabbage found during the experiments.

Insect pests and arthropods	Major season	Minor season
1. Cabbage Aphids	XXX	XXX
2. DBM	N	XX
3. Cabbage Webworm	XX	N
4. Variegated grasshopper	X	XX
5. Whitefly	XX	XX
6. Cabbage flea beetle	XX	XX
7. Cabbage white butterfly	X	X
8. Cabbage looper	X	X
9. Cotton leafworm	X	X
10. Mole cricket	X	XX
11. Millipede	X	XX
12. Snail	XX	X

XXX: Uncountable number XX: Many number X: Few number N: Not found.

4.1.1 Observed damage caused by the major pests on cabbage during the study period

4.1.1.1 Aphids

Cabbage aphids fed on plant sap and caused leaf cupping outward and inward. Attacked leaves appeared weak and wrinkled at the under surface. Large colonies of aphids fed on the underside of leaves (Plate 5), causing leaf curl, leaf discoloration, stunted growth, yellowing, wilting and death of infested plants. They also secrete sticky honeydew on which sooty mould grow. In addition, the aphid may transmit viruses which damage the cabbage plants.

Plate 5: Aphids infestation observed on a cabbage plant during the experiment.

4.1.1.2 DBM, *Plutella xylostella*

The larvae were the most destructive stage and fed on the underside of the leaf cutting round holes or more often scratching off the tissue leaving the epidermis of one side untouched, thus creating a transparent window. In the minor season, high infestations were observed as compared to the major season which recorded no infestation during the period of study.

4.1.1.3 Cabbage Webworm, *Hellula undalis*

The larvae fed on the growing points (apical meristem) (Plate 6) and the developing leaves (Plate 7). Larvae of *H. undalis* were found feeding on cabbage plants and some even cut the apical meristem of less established plants. Small larvae tunneled into the main stem which resulted in stunting and deformed plants. Their feeding on cabbage plant led to most multiple head formation in the major rainy season.

Plate 6: Cabbage webworm attacking the apical meristem of a young cabbage seedling.

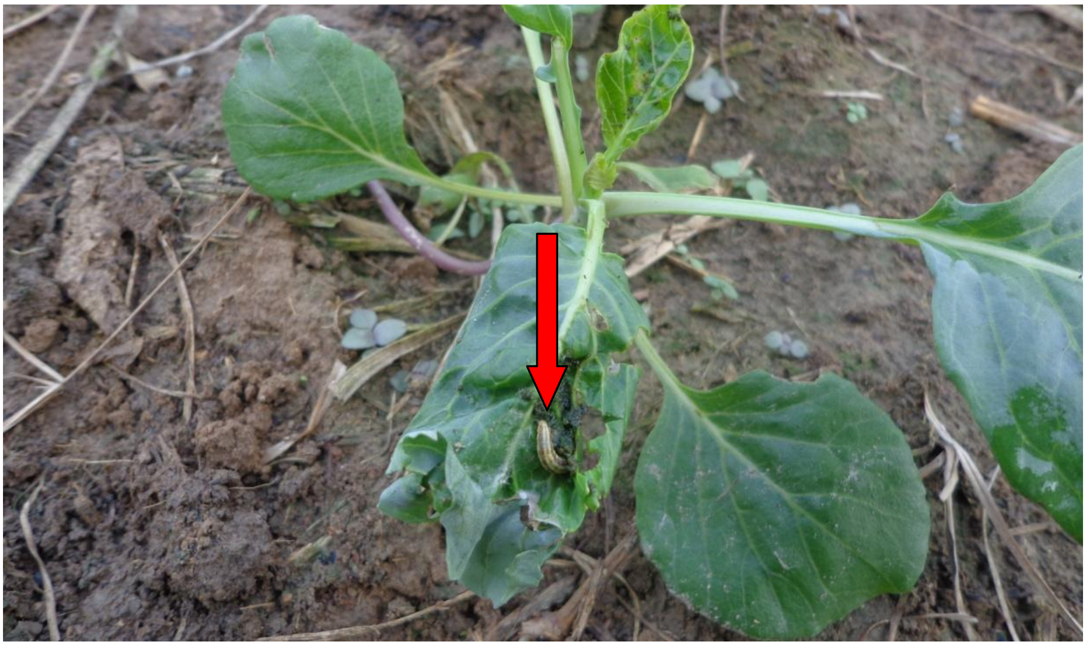


Plate 7: *Hellula undalis* attacking a developing cabbage leaf.

4.1.1.4 The variegated grasshopper, *Z. variegatus*

They were found feeding on the cabbage plants 2 days after the transplanting of seedlings. They chewed all the leaves of most young cabbage plants (Plate 8) and heads and hence decreased yield. In the dry season, high numbers of grasshoppers were found causing defoliation throughout the growing period of the crop.

Plate 8: Leaf damage caused by a variegated grasshopper on cabbage.

4.1.1.5 The African mole cricket

They attacked the stems of the young cabbage in the field. They burrowed into the ground soil around the plant and made its control very difficult. Other arthropods were also observed feeding on the cabbage, but their populations were too low to be considered. These included; the flea beetle, whitefly, snails and the millipedes, and other unidentified larvae and caterpillars (Plate 9 and 10).

Plate 9: A millipede causing damage to cabbage.

Plate 10: A snail feeding on the cabbage leaf.

4.1.1.6 Beneficial insects

However, natural enemies of pests of cabbage such as *Diaretiella rapae, Cotesia plutellae*, hoverflies, spiders, lady bird beetles (e.g. *Cheilomenes* spp.) and other beneficial arthropods were identified and observed attacking some insect pests.

4.2 Effects of botanicals and conventional insecticides on insect pest populations

Table 6a shows the effect of three levels of siam weed, neem and the conventional insecticide, sunhalothrin® on the mean number of major insect pests observed in the field experiment during the major rainy season of 2014. The results indicated that, the three rates of siam weed extracts were not significantly different from each other (Table 6a). However, the performance of siam weed extracts were similar to that of neem extract. The three rates of siam weed and neem extracts also had significantly lower number of aphids than the conventional insecticide, sunhalothrin®. In addition, siam weed extract applied at 10g/ L had fewer number of aphids than the control plots. The effect of all the botanicals and the conventional insecticide, sunhalothrin® were effective in managing the cabbage webworm, *H. undalis*. Moreover, they all performed better than the control plots where only water was sprayed.

Table 6a below shows no significant differences among treatments in the control of grasshopper, *Z. variegatus* for the major growing season. However, some botanicals (*Chromolaena odorata*- 10 and 20g/L) and the conventional insecticide, sunhalothrin® showed significantly lower numbers of other pests than the control. *Chromolaena odorata* extracts applied at 10 and 20g/L and sunhalothrin® at recommended rate performed better than the control in controlling other pests such as cabbage flea beetle (*Phyllotreta* spp.), cabbage white butterfly (*Pieris rapae*), cabbage looper (*Trichoplusia nii*), and *Spodoptera litorallis*.

Table 6a: Mean (±SE) populations of insect pests on cabbage sprayed with botanical and conventional insecticides and tap water as control, during 2014 major rainy season.

	Mean ± SE insect pests/ plant			
Treatments	***B. brassicae***	***H. undalis***	***Z. variegatus***	**Other pests[1]**
10g/L *C. odorata*	0.67 ± 0.22 c	1.38 ± 0.27 b	1.58 ± 0.26	1.83 ± 0.30 b
20g/L *C. odorata*	1.58 ± 0.29 bc	1.38 ± 0.28 b	1.29 ± 0.27	2.46 ± 0.31 b
30g/L *C. odorata*	1.58 ± 0.22 bc	1.79 ± 0.28 b	1.08 ± 0.24	2.63 ± 0.39 ab
50g/ L Neem	1.08 ± 0.28 c	1.13 ± 0.21 b	1.63 ± 0.29	3.04 ± 0.43 ab
Sunhalothrin®	3.33 ± 0.43 a	1.13 ± 0.23 b	1.38 ± 0.26	1.83 ± 0.34 b
Tap water	2.58 ± 0.58 ab	4.0 ± 0.56 a	1.63 ± 0.28	4.08 ± 0.35 a
F- Value	**7.44**	**11.13**	**0.67**	**5.56**
P	**<0.0001***	**<0.0001***	**0.647**	**<0.0001***

Means within a column for each treatment under each dose followed by different letters differ significantly from each other (P≤ 0.05).

[1]**Other pests:** cabbage flea beetle (*Phyllotreta* spp.), cabbage white butterfly (*Pieris rapae*), cabbage looper (*Trichoplusia ni*), and Cotton leafworm (*Spodoptera litorallis*).

Table 6b below showed that the botanicals had significantly lower number of aphids than the conventional insecticide, sunhalothrin® and the control in the minor growing season. However, there were no significant differences among all treatments in the control of *P. xylostella*, *Z. variegatus* and other pests.

Table 6b: Mean (±SE) populations of insect pests on cabbage sprayed with botanical and conventional insecticides and tap water as control during 2014 minor rainy season

	Mean ± SE insect pests/ plant			
Treatments	***B. brassicae***	***P. xylostella***	***Z. variegatus***	**Other pests[1]**
10g/L *C. odorata*	1.83 ± 0.22 b	4.50 ± 0.73	3.33 ± 0.48	1.67 ± 0.35
20g/L *C. odorata*	1.21 ± 0.25 b	3.13 ± 0.69	2.96 ± 0.43	0.88 ± 0.19
30g/L *C. odorata*	1.58 ± 0.32b	3.79 ± 0.64	3.08 ± 0.51	1.13 ± 0.25
50g/ L Neem	1.46 ± 0.26 b	3.08 ± 0.54	3.33 ± 0.50	1.13 ± 0.31
Sunhalothrin®	3.96 ± 0.64 a	4.13 ± 0.09	3.17 ± 0.50	1.46 ± 0.30
Tap water	3.75 ± 0.62 a	5.08 ± 1.01	4.46 ± 0.71	1.96 ± 0.32
F- Value	**7.61**	**1.02**	**1.06**	**1.67**
P	**<0.0001***	**0.4094**	**0.3831**	**0.1456**

Means within a column for each treatment under each dose followed by different letters differ significantly from each other (P≤ 0.05).

[1]**Other pests:** cabbage flea beetle (*Phyllotreta* spp.), cabbage white butterfly (*Pieris rapae*), cabbage looper (*Trichoplusia ni*), cabbage webworm (*Hellula undalis*) and Cotton leafworm (*Spodoptera litorallis*).

4.3 Effects of treatments on natural enemies

The results showed that there were no significant differences in the numbers of *D. rapae, C. plutellae* and hoverflies when the various treatments were applied. However, 20g/ L of *C. odorata* and neem had significantly high number of spiders compared to the other treatments. Also, for other natural enemies such as ladybird beetle (*Cheilomenes lunata*), earwigs, red ants (*Oecophylla* sp.) and mason wasp sampled, 20g/ L *C. odorata* treated plots had significantly high populations than that of sunhalothrin® (Table 7a).

Table 7a: Mean (±SE) numbers of natural enemies of pests of cabbage sprayed with botanical and conventional insecticides during 2014 minor rainy season.

	Mean ± SE natural enemies/ plant				
Treatments	***D. rapae***	***C. plutellae***	**Spider**	**Hoverfly**	**Other N.E[1]**
10g/L *C. odorata*	1.67 ± 0.64	1.58 ± 0.62	2.33 ± 0.41 ab	1.0 ± 0.35	1.25 ± 0.8 ab
20g/L *C. odorata*	2.38 ± 0.78	1.83 ± 0.50	2.58 ± 0.43 a	1.08 ± 0.22	1.50 ± 0.26 a
30g/L *C. odorata*	1.0 ± 0.43	0.83 ± 0.39	1.92 ± 0.40 ab	0.58 ± 0.25	0.42 ± 0.20 ab
50g/ L neem	1.13 ± 0.45	1.25 ± 0.34	2.67 ± 0.41 a	1.17 ± 0.35	1.13 ± 0.24 abc
Sunhalothrin®	2.29 ± 0.97	1.88 ± 0.53	0.83 ± 0.21 b	0.42 ± 0.15	0.29 ± 0.11 c
Tap water	2.5 ± 0.86	2.21 ± 0.58	1.96 ± 0.31ab	1.25 ± 0.38	0.67 ± 0.20 abc
F- Value	**0.84**	**0.95**	**3.22**	**1.27**	**4.82**
P	**0.5213**	**0.4536**	**0.0088***	**0.2792**	**0.0004***

Means within a column for each treatment under each dose followed by different letters differ significantly from each other ($P \leq 0.05$).

[1]**Other natural enemies:** ladybird beetle (*Cheilomenes lunata*), earwigs, red ants (*Oecophylla* sp.) and mason wasp

Table 7b shows the mean numbers of natural enemies sampled on the various treatment plots in the major rainy season. The result showed that 20g/L *C. odorata* had the highest number of *D. rapae* as compared to 30g/L *C. odorata*, neem and sunhalothrin®. The result again showed that, 20g/L *C. odorata*, neem and the tapwater (control) had the highest number of other natural enemies such as ladybird beetle (*Cheilomenes lunata*), Earwigs, Red ants (*Oecophylla* sp.) and Mason wasp as compared to the plots treated with the conventional insecticide, sunhalothrin®. Meanwhile, the results showed that there were no significant differences among all treatments in the number of spiders and hoverflies sampled (Table 7b).

Table 7b: Mean (±SE) numbers of natural enemies of pests of cabbage sprayed with botanical and conventional insecticides during 2014 major rainy season.

	Mean ± SE natural enemies/ plant			
Treatments	***D. rapae***	**Spider**	**Hoverfly**	**Other N.E[1]**
10g/L *C. odorata*	1.88 ± 0.57 ab	2.13 ± 0.30	0.63 ± 0.25	2.29 ± 0.42 ab
20g/L *C. odorata*	3.75 ± 0.63 a	2.00 ± 0.26	0.04 ± 0.05	3.50 ± 0.56 a
30g/L *C. odorata*	0.83 ± 0.21 b	1.63 ± 0.38	0.08 ± 0.09	2.83 ± 0.42 ab
50g/ L Neem	1.25 ± 0.38 b	2.08 ± 0.28	0.17 ± 0.09	3.50 ± 0.51 a
Sunhalothrin®	2.33 ± 0.75 b	1.17 ± 1.22	0.46 ± 0.24	1.46 ± 0.26 b
Tap water	2.29 ± 0.57 ab	2.00 ± 0.32	0.54 ± 0.29	3.38 ± 0.31 a
F- Value	**3.51**	**1.55**	**1.68**	**3.65**
P	**0.0051***	**0.1781**	**0.1433**	**0.004***

Means within a column for each treatment under each dose followed by different letters differ significantly from each other (P≤ 0.005).

[1]Other natural enemies: ladybird beetle (*Cheilomenes lunata*), earwigs, red ants (*Oecophylla* sp.) and mason wasp

4.4 Effects of treatments on cabbage head damage

Head damage were as a result of insects' holes in/or on cabbage leaves; which were mainly caused by DBM, cabbage webworms, the variegated grasshoppers and the millipedes in the growing seasons. There were no significant differences in the head damage among the treatments in the major season (Table 8). On the other hand, there was significant difference in the mean head damage among treatments in the minor rainy season. Cabbage heads from tap water or control plots had the highest head damage as compared to neem seed extract which had the lowest damage.

Table 8: Mean (±S.E) scores for head damage during 2014 major and minor seasons.

	Mean ± SE head damage/ plant	
Treatment	**Major rainy season**	**Minor rainy season**
10g/L *C. odorata*	3.17 ± 0.33 a	2.5 ± 0.28 ab
20g/L *C. odorata*	3.21 ± 0.29 a	2.96 ± 0.30 ab
30g/L *C. odorata*	3.13 ± 0.37 a	2.79 ± 0.32 ab
50g/ L Neem	1.96 ± 0.25 a	1.83 ± 0.27 b
Sunhalothrin®	3.04 ± 0.35 a	2.75 ± 0.27 ab
Tap water	3.04 ± 0.31 a	3.38 ± 0.31 a
F- Value	**2.20**	**3.03**
P	**0.0575**	**0.0126***

Means within a column for each treatment under each dose followed by different letter differ significantly from each other.

4.5 Effects of treatments on cabbage multiple head formation

Figure 1 shows the mean percent of multiple heads formed in the treatment plots during the two growing seasons. Tap water and 30g/L *C. odorata* treated plots had significantly high percentages of multiple heads formed in the major rainy season. Whiles, plots sprayed with 10 and 20g/L *C. odorata* and sunhalothrin® had significantly lower percentages of multiple head formed, with 50g/L neem having the least mean percent of multiple heads formed in the major season (Table 9). However, there were no significant differences in the percent mean of multiple heads formed during the minor season (Table 10).

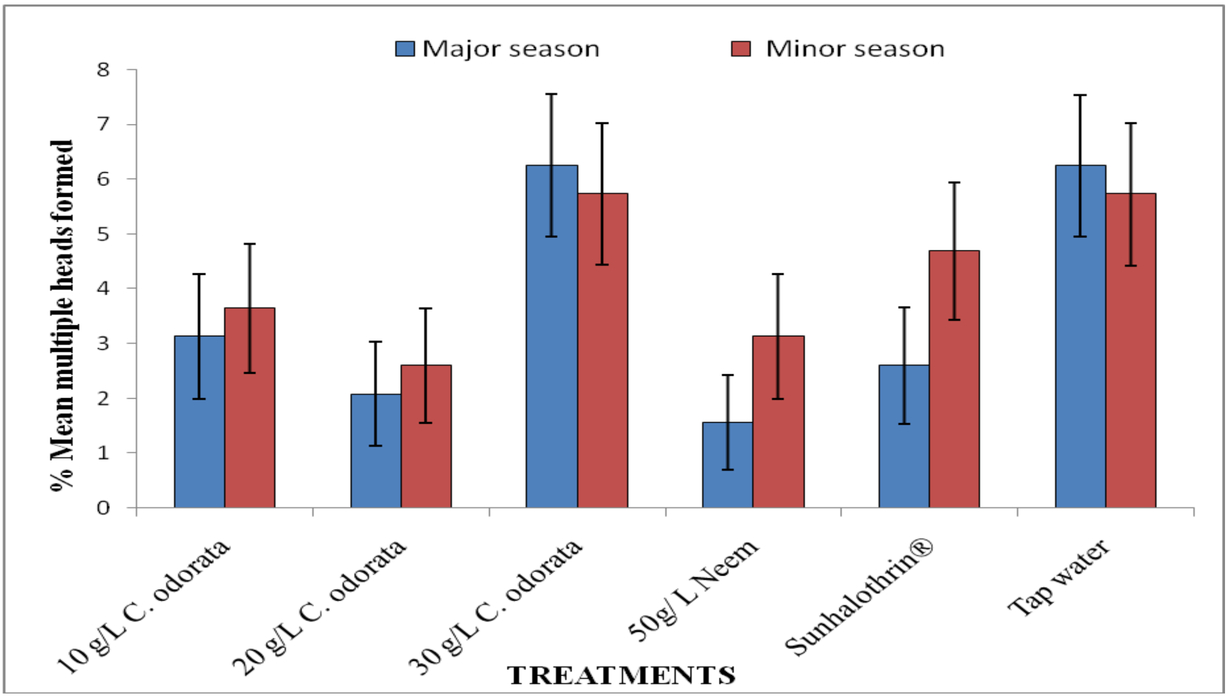


Figure 1: Effects of treatments on cabbage multiple heads formation during 2014 major and minor cropping seasons.

4.6 Effects of treatments on marketability of cabbage

Figures 2 and 3 shows the mean cabbage head or marketable yield acceptability compared to the unmarketable cabbage heads per plots as affected by the various treatments. In both seasons, the neem extract treated plots had the highest mean yield of marketable heads (ton/ ha) compared to the cabbage heads of the other treatments. There were no significant differences in the mean yields of marketable heads among the other sprayed treatments for both growing seasons, but differed from those of the tapwater treated plots. Also, there were no significant differences in the mean yield of unmarketable heads in all treatment plots for both major and minor seasons.

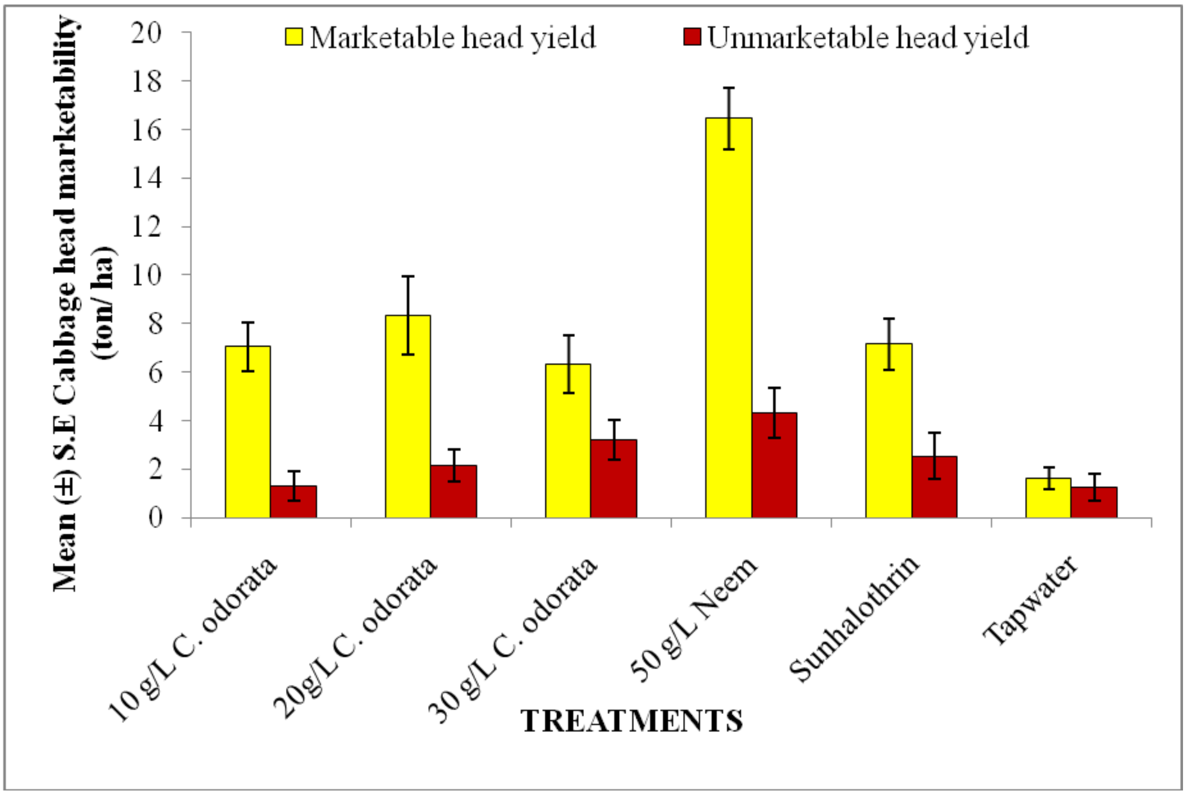


Figure 2: Effects of the various treatments on the mean yield of cabbage head marketability in the major season.

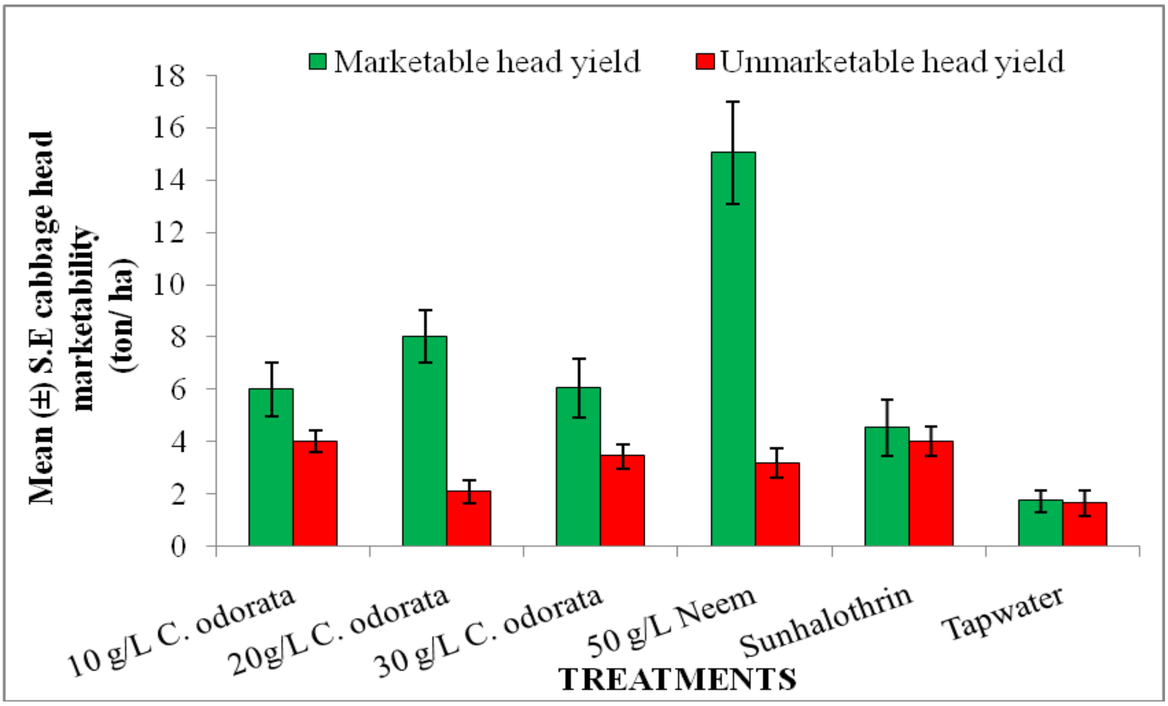


Figure 3: Effects of the various treatments on the mean yield of cabbage head marketability in the minor season.

4.7 Effects of treatments on weight of cabbage head

The gnawing, chewing and sucking activities of different insect pests on the leaves and heads of cabbage significantly reduced the mean weight of cabbage heads harvested during the growing periods (Table 9 and 10). Even though, there were significant differences among treatments in the major and minor rainy seasons, 2014 (Table 9 and 10), with Neem seed extract treated plots recording the highest mean weight for both major and minor rainy seasons of the year. The mean head weight differences among the three levels of *C. odorata*, Sunhalothrin® and tap water for both growing seasons were not significant. The mean yield of cabbages treated with *C. odorata* at 10 and 20g/L were significantly higher than that of tapwater.

Table 9: Mean (± S.E) number of multiple heads, weight of cabbage heads and yield of cabbage under different spray treatments during 2014 major rainy season.

		Mean ± SE:	
Treatments	**# of cabbage with multiple heads (%)**	**Weight per cabbage head (kg)**	**Total yield of cabbage (ton/ ha)**
10g/L *C. odorata*	3.13 ± 1.14 ab	0.21 ± 0.05b	8.37 ± 1.83 b
20g/L *C. odorata*	2.08 ± 0.95 ab	0.26 ± 0.05b	10.50 ± 2.19 b
30g/L *C. odorata*	6.25 ± 1.30 a	0.24 ± 0.05b	9.67 ± 1.95 b
50g/ L Neem	1.56 ± 0.87 b	0.52 ± 0.06a	20.75 ± 2.39 a
Sunhalothrin®	2.60 ± 1.07 ab	0.24 ± 0.05b	9.43 ± 1.88 b
Tap water	6.25 ± 1.29 a	0.20 ± 0.05b	3.30 ± 0.58 b
F- Value	**3.44**	**4.93**	**8.96**
P	**0.0059***	**0.0004***	**<0.0001***

Means within a column for each treatment under each dose followed by different letters differ significantly from each other (P≤ 0.005).

Table 10: Mean (± S.E) number of multiple heads, weight of cabbage heads and yield of cabbage under different spray treatments during 2014 minor rainy season.

	Mean ± SE:		
Treatments	**# of cabbage with multiple heads (%)**	**Weight per cabbage head (kg)**	**Total yield of cabbage (ton/ ha)**
10g/L *C. odorata*	3.65 ± 1.18 a	0.25 ± 0.03 b	10.04 ± 1.08 b
20g/L *C. odorata*	2.60 ± 1.05 a	0.25 ± 0.04 b	10.13 ± 1.60 b
30g/L *C. odorata*	5.73 ± 1.29 a	0.24 ± 0.03 b	9.56 ± 1.31 bc
50g/ L Neem	3.13 ± 1.14 a	0.47 ± 0.06 a	18.80 ± 2.45 a
Sunhalothrin®	4.69 ± 1.25 a	0.22 ± 0.03 b	8.99 ± 1.17 bc
Tap water	5.73 ± 1.30 a	0.17 ± 0.03 b	3.49 ± 0.62 c
F- Value	**1.20**	**7.14**	**10.82**
P	**0.3106**	**<0.0001***	**<0.0001***

Means within a column for each treatment under each dose followed by different letters differ significantly from each other (P≤ 0.005).

4.8 Economics of cabbage production

4.8.1 Yield and income

All the botanical treatments and the synthetic insecticide, sunhalothrin® in both growing seasons were financially profitable compared to the tap water or control treatment. Treated plots other than the control (untreated plots) had higher marketable head yields which resulted in income that exceeded the cost of production for the major rainy season whiles in the minor season, higher prices of marketable heads resulted in high income (Tables 12 and 11, respectiviely). There were differences in the total cost of treatments between the major and minor rainy seasons because there was one spray more in the minor season than in the major rainy season.

4.8.2 Cost: benefit ratio

In the minor rainy season, the 10 and 20g/ L *C. odorata* had better cost and benefit ratio as compared to 30g/L *C. odorata* as shown in Table 11 below. Also, neem had the best cost: benefit ratio of 1: 67.3 as compared with the sunhalothrin which had the lowest ratio of 1: 19.8 during the study period (Table 11). In the major rainy season, neem sprayed plots showed economic viability over the tap water control and had a ratio of 1:50.6. The other botanicals (Siam weed, *C. odorata*) had better cost and benefit ratios as compared to the conventional plots which gave the ratio of 1: 18.8 (Table 12).

Table 11: Evaluation of cost and benefit in managing cabbage pests with crude water extracts of Siam weed, neem and conventional insecticide, Sunhalothrin® during 2014 minor rainy season.

Treatment	Mean total yield per plant (ton/ha)	Marketable Head Yield (ton/ha)	Unmarketable head yield (ton/ha)	Cost of treatment (GHC/ha)	Income from Mktable head (GHC/ha)	Income from Unmktable head (GHC/ha)	Total Income (GH/ ha)	Net benefit (GHC/ha)	Benefit over Ctrl.	Cost: Benefit ratio
10g/L *C. odorata*	10.04 ± 1.08	6.01 ± 1.04	4.02 ± 0.42	400.00	15,025	4,020	19,045	18,645	12,635	1:31.6
20g/L *C. odorata*	10.13 ± 1.60	8.04 ± 1.02	2.10 ± 0.44	400.00	20,100	2,100	22,200	21,800	15,790	1:39.5
30g/L *C. odorata*	9.56 ± 1.31	6.07 ± 1.12	3.45 ± 0.45	400.00	15,175	3,450	18,625	18,225	12,215	1:30.5
50g/L Neem	18.80 ± 2.45	15.06 ± 1.95	3.20 ± 0.58	510.00	37,650	3,200	40,850	40,340	34,330	1:67.3
Sunhalothrin	8.99 ± 1.17	4.54 ± 1.07	4.02 ± 0.55	450.00	11,350	4,020	15,370	14,920	8,910	1:19.8
Tap water	3.49 ± 0.62	1.74 ± 0.42	1.66 ± 0.48	0.0	4,350	1,660	6,010	6,010	0	-

Table 12: Evaluation of cost and benefit of managing cabbage pests with crude water extracts of Siam weed, neem and conventional insecticide, Sunhalothrin® during 2014 major rainy season

Treatment	**Mean total yield per plant (ton/ ha)**	**Marketable Head Yield (ton/ ha)**	**Unmarketable head yield (ton/ha)**	**Cost of treatment (GHC/ha)**	**Income from Mktable head (GHC/ha)**	**Income from Unmktable head (GHC/ha)**	**Total Income (GH/ ha)**	**Net benefit (GHC/ha)**	**Benefit over Ctrl.**	**Cost: Benefit ratio**
10g/L *C. odorata*	8.37 ± 1.83	7.05 ± 1.02	1.32 ± 0.60	350.00	10,575	660	11,235	10,885	7,785	1:22.2
20g/L *C. odorata*	10.50 ± 2.19	8.32 ± 1.61	2.15 ± 0.65	350.00	12,480	1,075	13,555	13,205	10,105	1:28.9
30g/L *C. odorata*	9.67 ± 1.95	6.31 ± 1.19	3.22 ± 0.81	350.00	9,465	1,610	11,075	10,725	7,625	1:21.8
50g/L Neem	20.75 ± 2.29	16.45 ± 1.25	4.33 ± 1.05	460.00	24,675	2,165	26,840	26,380	23,280	1:50.6
Sunhalothrin	9.43 ± 1.88	7.17 ± 1.05	2.55 ± 0.95	450.00	10,755	1,275	12,030	11,580	8,480	1:18.8
Tap water	3.30 ± 0.58	1.65 ± 0.45	1.25 ± 0.55	0.0	2,475	625	3,100	3,100	0	-

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Effects of the treatments on insects population

The findings from this research have demonstrated that, the production of cabbage in the moist deciduous agro-ecological zone can be affected by numerous insect pests among such are cabbage aphids (*B. brassicae*), DBM (*P. xylostella*), cabbage webworm (*H. undalis*), grasshopper (*Z. variegatus*), cabbage flea beetle (*Phyllotreta* spp.), cabbage white butterfly (*Pieris rapae*), cabbage looper (*Trichoplusia ni*), Cotton leafworm (*Spodoptera litoralis*) and other arthropods.

Insect pests sampled on the cabbage field in the major season were slightly lower compared to those that were present in the minor season (Table 5). The results showed that the presence and abundance of the insect pests differed during the two seasons and this could be attributed to seasonal and climatic differences. Also, surprisingly diamondback moth, *P. xylostella* was not found on the treatment plots during the major season. The reasons may be attributed to the dominance of the natural enemies such as predators and parasites that feed on them and natural elements such as rainfall, which washes off the eggs, larvae, pupae and the adults from the plant to the soil where they are destroyed during the period.

However, population of aphids, *B. brassicae*, was dominant throughout both seasons and was reduced as a result of the application of the treatment with siam weed and neem seed extracts. This was especially observed in the 10g/L *C. odorata* and neem seed extracts plots in both the minor and the major seasons. This reduction was due to the toxic effect of the plants. Botanicals and plant - based insecticides have been noted for their larvicidal effects (Sanda *et al*., 2006; Ogendo *et al*., 2008; Agboka *et al*., 2009). The effectiveness of siam weed and neem seed extracts in the study were generally better as compared to the conventional insecticide in the control of aphid. This may be due the fact that *B. brassicae* may gradually be developing resistance to the conventional insecticides (Fening *et al.* 2013). The performance of the plant extracts in reducing the population of *B. brassicae* indicates their usefulness in controlling insect pests when incorporated into Integrated Pest Management (IPM). The efficacy of the botanical treatments against *B. brassicae* is supported by the findings of previous studies on this insect pest. For instance, the extracts of *Azadirachta indica* and *Melia azedarach* have been successfully used to control infestations of cabbage aphids (Rando *et al.*, 2011 and Kibrom *et al*., 2012).

Also, the 10 and 20g/L *C. odorata* performed better as compared to the 30g/L *C. odorata* in the control of other pests such as *T. ni*, *P. rapae*, *S. littorallis* and *Phyllotreta* spp. Other herbivores species found on both botanical and conventional treated plots did not differ significantly among the various treatments. *Plutella xylostella* was dominant during the minor season on the treatment plots. Moreover, there was no significant difference in their level of infestations. Cabbage webworm, *H. undalis* was dominant during the major rainy season due to favourable weather conditions. The variegated grasshopper, *Z. variegatus* and other arthropod pests were also found in both seasons but were more destructive in the minor rainy season. According to the findings of Ayalew (2006), yield losses of cabbage may be due to insect pest and vary depending on the season and severity of pest infestation.

Monoculture enhanced pest infestation on cabbage by lepidopterous insects and aphids since it created conducive environment for particular insect pest to flourish (Kumar, 1986).

5.2 Effects of treatments on natural enemies population

High incidence of natural enemies per plot is dependent upon the number of insect pests present, the toxicity of the treatments and the vigorous growth and succulence of the plant. Ideally, insecticides used in controlling insect pests should either have less impact on natural enemies or promote their build- up. The number of parasitoids and predators observed on the cabbage treated plot was somewhat not different from that of the control. In the minor rainy season, *D. rapae* and *C. plutellae* showed no significant difference due to less toxicity of the treatments on the beneficial insects. For instance, neem products have been proved to be harmless to beneficial insects and environmentally friendly (Borror *et al*., 1992).

However, the 20g/ L *C. odorata* treated plots in the major season performed better in ensuring the survival of *D. rapae* than the 30g/L *C. odorata* treated plot, and also more other natural enemies such as ladybird beetle (*Cheilomenes lunata*), earwigs, red ants (*Oecophylla sp.*) and mson wasp than the conventional insecticide, sunhalothrin in both the major and minor seasons during the study. The effectiveness of 20g/ L *C. odorata* may be attributed to its low toxicity of the treatment on the beneficial insects, hence making them available and thereby promoting high level parasitism and predation (Charleston, 2004).

5.3 Effects of treatments on cabbage head damage

Cabbage is prone to insect pest attack and the tendency to produce healthy and quality cabbage heads with low insecticide residue to meet consumers demand has been a problem yet to be solved. A study conducted in the South Western Ontario in Canada concluded that attack by insect pests alone contributed significantly to yield loss of cabbage by 50% (Tolman *et al.*, 2004). Meanwhile, DBM which is a cosmopolitan pest of crucifers cause a significant yield loss of 20- 100% and up to 60% on cabbage in India and Ghana, respectively (Chellaiah and Srinivasan, 1986; Lingappa *et al.*, 2004; Obeng- Ofori *et al.*, 2007; Fening *et al.*, 2013). In the study, it was observed that the three rates of *C. odorata*, neem and sunhalothrin® were most active against insect pests causing damage to cabbage heads as compared with control plot in the minor season. Fening *et al.*, 2011, however, revealed that the use of plant extracts in IPM provides added advantage over the use of synthetic insecticide; as, they are not persistent in the environment, readily available, affordable and easily made.

5.4 Effects of treatments on multiple heads formation

Higher significant percentages of multiple heads were formed on untreated plots as compared to treated plots. These findings indicated that cabbage cannot be cultivated without making an attempt to control insect pests because like other crucifers, they contain mustard oil and glucosides (Gupta and Thorsteinson, 1960) which make them more susceptible to insect pest attack especially cabbage webworm, *H. unadalis*.

5.5 Effects of treatments on marketability of cabbage

Marketable cabbage heads harvested from the treated plots were significantly higher as compared to that from control plots which had significantly higher mean weight of unmarketable heads for both major and minor seasons. This may result from the treatments offering some level of protection against the key pests of cabbage. Neem treated plots in both seasons recorded the highest significant mean marketable heads compared to the other treatment plots. This might be as a result of the numerous effects of the neem extract on the crop pests through their repellency effect, antifeedant effect by preventing insects from laying eggs or as inhibitors by interfering with insect life cycle (Kareru *et al*., 2013).

5.6 Effects of treatments on weight of cabbage head

The significant performance of the cabbage heads among the various treatments during the major and minor rainy seasons respectively were attributed to the treatment effects. However, other factors may have accounted for the yield performance, such as the existing insect pest pressure, land use history, crop resilience, soil fertility and prevailing climatic conditions (Fening *et al*., 2014). High yield of cabbage head was recorded on treated plots against that of control plot with Neem seed extract treated plots recording the highest mean weight of cabbage heads due its insecticidal ability. This result confirms the findings of Landis *et al*., (2000), that acqueous neem seed extracts (ANSE) applied at 50- 70 g/L provided good protection against collard insect pests and increased dry matter content significantly.

5.7 Cost: benefit ratio

Cost: benefit ratio is an indicator of the relative economic performance of the treatments (Aziz *et al*., 2012, Amoabeng *et al*., 2014). A ratio of more than one indicates the economic viability of the treatment. Economic analysis, however, is useful because besides the spray type applied: all other input costs were constant for all treatments (Amoabeng *et al*., 2014). The cost: benefit ratio, the total income and the benefit obtained from each treatment is greatly influenced by the price of the commodity. The results in the study show that the cost: benefit ratios in the minor rainy were slightly higher for treatments as compared to that of the major rainy season. This may be attributed to the price of cabbage heads which was higher (50%) in the minor season harvest than the major season yield.

In the study, cabbage heads from plots sprayed with the conventional, sunhalothrin® and those from the botanical plots were sold for the same price. If cabbage heads from plots protected with botanicals were sold for premium price, then, there would be corresponding increases in the economic benefit. In the developed countries where human health is of paramount importance, there are premium prices for food commodities that do not have pesticide contamination and health- conscious consumers eagerly patronize (Njoroge and Manu, 1999; Amoabeng *et al*., 2014).

However, in Ghana, food commodities including vegetables such as cabbage on the market are not currently identified as organic and conventional. Organic food producers in developing countries should raise awareness of the benefits of pesticide- free food commodities to obtain the deserved prices for their commodities and subsequently obtain higher benefit and also have access to export commodities to the US and EU markets (Njoroge and Manu, 1999; Amoabeng *et al*., 2014).

The study has shown that the 10g/L and 20g/L of *C.odorata* extracts were effective in the management of insect pests, less detrimental to natural enemies and also economical to use than the higher rate, 30g/L *C. odorata* extracts. This finding has therefore offered a remedy to Amoabeng *et al*., (2013) who applied *C. odorata* extract at 30g/L and was effective in the control of insect pests but was more detrimental to the survival of natural enemies. Thus, *C. odorata* applied at 10- 20g/L of water and also neem at 50g/L are recommended for use by small scale cabbage farmers (especially those in organic farming systems) to ensure food and environmental safety (Fening, 2013).

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

The awareness regarding food safety has increased the demand for organically produced food. Globally, the non-pesticide management (NPM) of crops is becoming popular among vegetable farmers since it endeavours to keep the control of insect pests and crop cultivation costs to a minimum and avoid dependency on manufactured inputs by utilizing plant materials that are readily available to farmers. The study has demonstrated that there is some potential for the use of lower rates of *C. odorata* extracts at 10- 20g/ L and neem seed extract to control some of the major pests of cabbage and conveniently maintain ecological balance with their natural enemies on cabbage plants and also have increase in yield. The advantage of using the Siam weed and neem extract is that they are cheap and easy to prepare especially the siam weed. However, further work is required to fine- tune its extraction so that optimum amount of the active ingredient could be obtained.

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APPENDICES

Appendix 1: ANOVA for the effects of botanicals and conventional insecticides on insect pest population

ANOVA for *B. brassicae* in the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	116.55556	23.3111	7.4379	<.0001*
Reps.	2	27.76389	13.8819	4.4293	
Error	136	426.23611	3.1341		
C. Total	143	570.55556			

ANOVA for *H. undalis* in the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	146.70139	29.3403	11.1348	<.0001*
REPS	2	2.09722	1.0486	0.3980	
Error	136	358.36111	2.6350		
C. Total	143	507.15972			

ANOVA for *Z.variegatus* in the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	5.80556	1.16111	0.6699	0.6470
REPS	2	1.76389	0.88194	0.5088	
Error	136	235.73611	1.73335		
C. Total	143	243.30556			

ANOVA for other pests in the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	85.89583	17.1792	5.5556	0.0001*
REPS	2	0.50000	0.2500	0.0808	
Error	136	420.54167	3.0922		
C. Total	143	506.93750			

ANOVA for *B. brassicae* in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	179.61806	35.9236	7.6087	<.0001*
Reps.	2	0.43056	0.2153	0.0456	
Error	136	642.11111	4.7214		
C. Total	143	822.15972			

ANOVA for *P. xylostella* in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	73.7847	14.7569	1.0183	0.4094
REP.	2	6.0139	3.0069	0.2075	
Error	136	1970.8611	14.4916		
C. Total	143	2050.6597			

ANOVA for *Z. variegatus* in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	35.47222	7.0944	1.0642	0.3831
Reps	2	26.09722	13.0486	1.9573	
Error	136	906.65278	6.6666		
C. Total	143	968.22222			

ANOVA for other pests in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	17.20139	3.44028	1.6716	0.1456
Reps.	2	8.22222	4.11111	1.9975	
Error	136	279.90278	2.05811		
C. Total	143	305.32639			

Appendix 2: ANOVA for the Effects of the treatments on the natural enemies

ANOVA for *D. rapae* in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	52.1181	10.4236	0.8432	0.5213
Reps.	2	7.3889	3.6944	0.2989	
Error	136	1681.1528	12.3614		
C. Total	143	1740.6597			

ANOVA for *C. plutellae* in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	29.05556	5.81111	0.9459	0.4536
Reps.	2	6.09722	3.04861	0.4963	
Error	136	835.48611	6.14328		
C. Total	143	870.63889			

ANOVA for spiders in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	54.03472	10.8069	3.2241	0.0088*
Reps.	2	2.76389	1.3819	0.4123	
Error	136	455.86111	3.3519		
C. Total	143	512.65972			

ANOVA for hoverfly in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	13.66667	2.73333	1.2729	0.2792
Reps.	2	3.29167	1.64583	0.7664	
Error	136	292.04167	2.14737		
C. Total	143	309.00000			

ANOVA for other natural enemies in the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	28.50000	5.70000	4.8224	0.0004*
Reps.	2	4.50000	2.25000	1.9036	
Error	136	160.75000	1.18199		
C. Total	143	193.75000			

ANOVA for *D. rapae* in the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	124.3056	24.8611	3.5115	0.0051*
REPS	2	64.3889	32.1944	4.5473	
Error	136	962.8611	7.0799		
C. Total	143	1151.5556			

ANOVA for spiders in the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	16.58333	3.31667	1.5512	0.1781
REPS	2	2.62500	1.31250	0.6138	
Error	136	290.79167	2.13817		
C. Total	143	310.00000			

ANOVA for hoverflyin the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	7.63889	1.52778	1.6809	0.1433
REPS	2	6.05556	3.02778	3.3312	
Error	136	123.61111	0.90891		
C. Total	143	137.30556			

ANOVA for other natural enemiesin the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	80.78472	16.1569	3.6469	0.0040*
REPS	2	19.34722	9.6736	2.1835	
Error	136	602.52778	4.4304		
C. Total	143	702.65972			

Appendix 3: ANOVA for the effects of treatments on cabbage head damage:

In the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	27.36806	5.4736	2.2033	0.0575
Reps.	2	22.93056	11.4653	4.6151	
Error	136	337.86111	2.4843		
C. Total	143	388.15972			

In the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	31.78472	6.35694	3.0314	0.0126*
Reps.	2	3.18056	1.59028	0.7584	
Error	136	285.19444	2.09702		
C. Total	143	320.15972			

Appendix 4: ANOVA for the effects of treatment on multiple head formation:

In the major season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	520.8333	104.167	3.4376	0.0059*
Reps.	2	6.5104	3.255	0.1074	0.8982
Error	136	4121.0937	30.302		
C. Total	143	4648.4375			

In the minor season

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	213.7587	42.7517	1.2041	0.3106
Reps.	2	8.6806	4.3403	0.1222	0.8850
Error	136	4828.5590	35.5041		
C. Total	143	5050.9983			

Appendix 5: ANOVA for the effects of treatments on marketable and unmarketable cabbage heads.

ANOVA for marketable cabbage head in the major season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	1.690834	0.338167	5.2857	0.0002*
Reps.	2	0.851391	0.425695	6.6539	
Error	136	8.700891	0.063977		
C. Total	143	11.243115			

ANOVA for unmarketable cabbage head in the major season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	0.0837557	0.016751	1.3854	0.2336
Reps.	2	0.0255045	0.012752	1.0547	
Error	136	1.6444347	0.012091		
C. Total	143	1.7536949			

ANOVA for marketable cabbage head in the minor season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	1.5734765	0.314695	6.8949	<.0001*
Reps.	2	0.1956544	0.097827	2.1434	
Error	136	6.2072698	0.045642		
C. Total	143	7.9764007			

ANOVA for unmarketable cabbage head in the minor season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	0.02573852	0.005148	1.3404	0.2510
Reps.	2	0.00675464	0.003377	0.8794	
Error	136	0.52228495	0.003840		
C. Total	143	0.55477811			

Appendix 6: ANOVA for the effects of treatments on weight and total yield of cabbage head .

ANOVA for cabbage head weight in the major rainy season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	1.560578	0.312116	4.9331	0.0004*
Reps.	2	0.821725	0.410863	6.4938	
Error	136	8.604686	0.063270		
C. Total	143	10.986989			

ANOVA for total cabbage yield in ton/ ha for the major season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	3915.072	783.014	8.9610	<.0001*
Reps.	2	678.858	339.429	3.8845	0.0229*
Error	136	11883.781	87.381		
C. Total	143	16477.711			

ANOVA for cabbage head weight in the minor rainy season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	1.2974452	0.259489	7.1369	<.0001*
Reps.	2	0.1485852	0.074293	2.0433	
Error	136	4.9447981	0.036359		
C. Total	143	6.3908285			

ANOVA for total cabbage yield in ton/ ha for the minor season.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TREATMENTS	5	2900.048	580.010	10.8147	<.0001*
Reps.	2	160.505	80.252	1.4964	0.2276
Error	136	7293.887	53.632		
C. Total	143	10354.439			