EVALUATION OF SIX PEST MANAGEMENT STRATEGIES ON KEY INSECT PESTS OF TWO CABBAGE VARIETIES (*Brassica oleracea* var. *capitata* L.) IN THE KETU SOUTH MUNICIPALITY OF THE VOLTA REGION OF GHANA.

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DECLARATION

I, Nkafu Therese Ngosong, author of this thesis titled 'Evaluation of six pest management strategies on key insect pests of two cabbage varieties (*Brassica oleracea* var. *capitata* l.) in the Ketu South municipality of the Volta region of Ghana', do hereby declare that apart from references of other people's work which have been duly acknowledged, the research work presented in this thesis was done entirely by me under the supervision of Professor Kwame Afreh-Nuamah and Doctor Ken Okwae Fening, for the award of Master of Philosophy (MPhil) in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS), University of Ghana, Legon, from July 2016 to July 2017. This work has never been presented in whole or in part for any other degree in this University or elsewhere.

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DR. ROSINA KYEREMATEN (ARPPIS CO-ORDINATOR)

ABSTRACT

Cabbage is a well-known vegetable grown in Ghana due to its nutritional value and serves as a source of livelihood for small scale farmers. Its cultivation is constraint by insect pests such as *Plutella xylostella* (L) (Lepidoptera: Plutellidae), *Hellula undalis* (Lepidoptera: Crambidae) and *Brevicoryne brassicae* (Aphididae) which cause significant damage and yield loss. Farmers especially those in the Ketu South municipality of the Volta region apply synthetic insecticides 12-15 times in one season to produce damage free cabbage heads and this method of control has been proven to be detrimental to consumers, natural enemies and the environment. It is against this background that an effective and environmentally friendly approach considering biopesticide, botanical and shallot as a repellent crop was explored in this study. Two cabbage varieties, Oxylus and KK cross were subjected to six pest management strategies; aqueous neem seed extract (75kg/ha at 50g/l of water), Bypel 1® (PrGV+Bt) (2kg/ha at 1.5g/l of water), shallots planted 14 days prior to cabbage transplanting, shallot planted 7 days prior to cabbage transplanting and shallot planted with cabbage on the same day combined with a short duration of neem spray and untreated control for two seasons in 2016/2017. The experiment was set up in a completely randomized design with a split-plot treatment arrangement with three replications. Main plots were the cabbage varieties whilst the sub plots were the six pest management strategies. The two biopesticides were applied after the first sampling of insects and thereafter every week. The results showed that plots treated with Bypel 1® had the least number of *P. xylostella*, and *H. undalis* but did not differ significantly ($F_{5, 22} = 6.17$, $P = 0.0010$ and $F_{5, 22} = 45.98$, $P = < 0.0010$ *P. xylostella* both seasons; $F_{5, 22} = 4.77$, $P = 0.0040$ and $F_{5, 22} = 9.05$, $P < 0.0010$ *H. undalis* both seasons) from the other treatments, except for the control which had the highest population. Shallot planted the same time with cabbage sprayed with a short duration of neem had the lowest aphid score (0 and 1) with the highest on control plots (4 and 5). Other insect pests observed in the field were *Bemisia tabaci, Thrips tabaci, Trichoplusia ni, Zonocerus variegatus* and *Empoasca* spp. Fewer numbers of *T. tabaci, T. ni, Z. variegatus* were recorded on Bypel 1® and aqueous neem seed extract treated plots, but no significant differences were observed with other pest management strategies except in the control plots. *B. tabaci* numbers were least in Bypel 1® and Neem plots and highest in control plots. Apart from *P. xylostella* and *H. undalis* whose populations were highest on KK cross, the oxylus variety had higher populations of all the other pests but differences were not significant, except for *B. tabaci* with a significantly higher population on oxylus. The interactions between varieties and various strategies on *P. xylostella*, *H. undallis* and *B. brassicae* numbers for both seasons were not significant ($F_{5, 22}$ = 0.18, P = 0.9690 and $F_{5, 22}$ = 0.44, P = 0.8180 for *P. xylostella*; $F_{5, 22}$ = 0.55, P = 0.7380 and $F_{5, 22}$ = 0.61, P = 0.6960 for *H. undalis* and $F_{5, 22}$ = 0.22, P = 0.9480 and $F_{5, 22}$ = 0.34, P = 0.8840 for *B. brassicae*, respectively), indicating that the two varieties responded to the six pest management strategies in a similar manner. Shallot plots planted 14 days before transplanting cabbage had the highest numbers of the natural enemies (hoverflies, ladybirds and spiders) while *C. plutellae* was highest on shallot planted 7 days prior to cabbage transplanting and control plots. The yield and marketability of cabbages from the various pest management treatments were ranked in the following order of decreasing magnitude: Bypel 1® > sole neem > shallot with short duration Neem > shallot planted 14 days prior cabbage > shallot planted 7 days prior cabbage > control. Oxylus produced medium size heads which were more marketable and stored longer than KK cross with larger heads and greater head rots. This study demonstrated the potential of biopesticides and shallot as a repellent crop in the management of insect pests of cabbage. This could contribute to boosting the vegetable (cabbage) growing industry and positively impact on vegetable farmers' livelihood in the Volta region and the physical health of consumers.

DEDICATION

I dedicate this thesis to my beloved father, Ntimeh Charles Nkafu, who valued education and did all he could so I would receive quality education. The moral and spiritual support and examples of hard work provided by my mother, Akohngwa Helen Nkafu and little Danny have been my inspiration.

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LIST OF ABBREVIATIONS

$US – United States Dollars

ANOVA – Analysis of Variance

ARPPIS – African Regional Postgraduate Programme in Insect Science

AVRDC – Asian Vegetable Research and Development Center

CABI – Centre for Agriculture and Biosciences International

DAAD – German Academic Exchange Service

DBM – Diamondback moth

FAO – Food and Agriculture Organization of the United Nations

HPLC – High Performance Liquid Chromatography

IFOAM – International Federation of Organic Agriculture Movements

IGR – Insect Growth Regulator

ISOFAR – International Society of Organic Agriculture Research

ISSAAS – International Society for Southeast Asian Agricultural Sciences

ISSN – International Standard Serial Number

JENRM – Journal of Energy and Natural Resources Management

LSD – Least Significant Difference

MoFA – Ministry of Food and Agriculture

SE – Standard Error

WAAPP – West African Agricultural Productivity Programme

WHO – World Health Organization

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Introduction

Vegetables are an important source of minerals, vitamins, and proteins in human diets throughout the world and are central to most nutrition, food security and poverty reduction programmes (Hartmann, 2010). Cabbage, *Brassica oleracea* var. *capitata* L. (Brassicaceae), is an exotic leafy vegetable that originated from the Mediterranean Region, Southern England, Wales and Northern France (Norman, 1992), but is now cultivated extensively all-year-round throughout the world including African countries (FAO/WHO, 1995; Obeng-Ofori, 1998). Traditionally, cabbage has been used to cure certain ailments. The ancient Greeks used juice of fresh white cabbage to relieve sore or infected eyes and juice from the cabbage stem is a good remedy for ulcers (Norman and Shealy, 2007). Cabbage is usually used for stews, soups, sandwishes and hamburgers and also eaten as fresh cut salad (Norman, 1992; Van der Vossen and Seif, 2004; Baidoo *et al*., 2012). It contains chemicals which can prevent cancer and has anti-inflammatory property (Lin, 2008). Furthermore, this cruciferous vegetable is low in saturated fat, cholesterol, high in dietary fiber, vitamin K, foliate, potassium, manganese, vitamin C, vitamin A, thiamin, vitamin B6, calcium, iron and magnesium for healthy body development.

Cabbage in Ghana is mostly grown in Greater Accra, Ashanti, Brong Ahafo and Volta Regions. A conscious effort to improve diet has resulted in cabbage becoming a popular vegetable in the Volta region and is cultivated in home gardens and in peri-urban environments such as low lands naturally flooded by rainwater or on small fields around towns, villages and the Volta Lake (Amengor *et al*., 2015).

Nevertheless, cabbage cultivation in the Volta region is confronted with many constraints, especially insect pest infestation. Like other brassicas, a wide spectrum of pests cause considerable damage to cabbage leaves, stems, growing point, inflorescence and heads (CPC, 2001b), whose feeding results in significant yield losses. Amongst these pests, the diamondback moth, (DBM) - *Plutella xylostella* (L) (Lepidoptera: Plutellidae), the cabbage webworm, - *Hellula undalis* (Lepidoptera: Crambidae) and the cabbage aphid, - *Brevicoryne brassicae* (Aphididae) have been noted as key pests in Ghana (Mochiah *et al.*, 2011a, 2011b; Amoabeng *et al.*, 2013; Fening *et al.*, 2013, 2014a). Baseline studies conducted under the West African Agricultural Productivity Programme (WAAPP) project in the Ketu South Municipality –Volta Region to identify constraints faced by cabbage farmers also identified *P. xyllostela* as a key pest (Amengor *et al*., 2015). Heavy infestation by *P. xylostella* and *B. brassicae* can result in crop losses of up to 90% and 70-80%, respectively (Talekar and Shelton, 1993; Furlong *et al*., 2008). Globally, the estimated cost of control and yield loss by DBM alone is estimated to be US$ 4billion and US$ 5 billion per annum (Zalucki *et al*., 2012; Wei *et al*., 2013).

The control of cabbage pests including DBM, cabbage webworm and cabbage aphids in the Ketu south municipality of Ghana and other African countries is solely dependent on synthetic insecticides such as Cypermethrin, Pyrinex® (chlorpyrifos) and K optimal® (lambda + acetamiprid) throughout the growing season. The use of synthetic pesticides though valued for their convenience and reliability, also pose undesirable side effects to agro ecosystems and health hazards to both producers and consumers in the value chain (Dadang *et al*., 2009). Therefore, the attempt to reduce synthetic pesticides is yet a challenge to be fully resolved through the promotion of Integrated Pest Management (IPM) strategies.

1.2 Problem Statement and Justification

The cultivation of cabbage provides livelihood to a large population in Ghana, due to its growing popularity for the food industry and home consumption (Abbey and Manso, 2004; Mochiah *et al.*, 2011a). For example, in 2006, there were about 800-1,000 farmers engaged in commercial urban vegetable farming where the vegetable produced were eaten by more than 200,000 urban dwellers daily in Accra (Obuobie *et al.*, 2006). Nevertheless, a complex of pests occurs whenever cruciferous crops are cultivated leading to quality and quantity yield losses. Tolman *et al*. (2004) recorded a significant yield loss of 50% on cabbage due to attack by insect pests alone in Canada. Of these insect pests, *P. xylostella*, *H. undalis* and *B. brassicae* are of major concern. During the end of year evaluation of challenges encountered by cabbage farmers in the Ketu South municipality in the Volta region of Ghana, farmers through agricultural extension officers also identified *P. xylostella* as a serious pest responsible for little or no marketable yield and in some cases have caused farmers to abandon cabbage to the cultivation of other vegetables in the area. Since efforts to control costs and reduce losses remain a driving force in agricultural research (Schwartz and Klassen, 1981), the district Director requested for a solution to the problem. To this regard, baseline studies conducted in this locality showed 12-15 synthetic insecticide spray per cropping season (Amengor *et al*., 2015), with the increased spray frequency attributed to ineffectiveness of most insecticides.

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 insect pests. The safest and sustainable way of controlling cabbage pests is to augment several control options but in Ghana and other African countries, farmers in their quest to achieve immediate results rely on high doses of synthetic insecticides at short intervals in order to suppress pest populations (Mawuenyegah, 1994; Ntow *et al*., 2006; Jin *et al*., 2017) and produce marketable heads that meets the consumer demand for unblemished produce.

Nonetheless, synthetic pesticides while valued for their convenience do not only increase production cost but pose environmental and health implications as well as effects on the natural enemies of the pests (Obeng-Ofori *et al*., 2002; Timbilla and Nyarko, 2004). Though new insecticides are being developed, diamondback moth however, can cause severe damage even with application of several different insecticides because of its ability to develop resistance to all major groups of insecticides (Wright *et al.,* 1997; YuXian *et al*., 2001).

As hazards of broad-acting pesticides are documented, pesticides that are toxic only to the target pest, have low toxicity to non-target organisms including beneficial insects (Liu *et al*., 1999), and fewer environmental hazards are sought. One of such pesticide is Bypel 1® (PrGV+Bt), a naturally occurring bacteria used as natural pesticide. It is environmentally friendly and gives an excellent control of leaf eating caterpillars without harming beneficial insects and the scope of its efficacy and effectiveness should be broaden amongst cabbage farmers in the Ketu South municipality in the Volta region. The use of botanicals (insecticides derived from plants) appears to be the most promising (Buss and Park-Brown, 2002), in terms of safety, rapid breakdown, ease of preparation and cost. Mordue and Blackwell (1993) showed that the use of neem

(*Azadirachta indica*) extracts was effective against several pests and the probability of insect resistance against its ingredients is generally low (Volinger, 1995) whilst Schmutterer and Singh (1995) demonstrated the insecticidal activity of azadirachtin against 400 species and subspecies of insect pests. However, Afreh-Nuamah *et al*. (2006) reported that the use of neem insecticides should be augmented with other compatible control methods to ensure optimum protection of insect pests in cowpea.

More so, cultural practices such as planting insect pest repellent crops in intercropping offer less reliance on chemical control since they house a greater diversity of insects, especially natural enemies, reduce pest populations, increase yields and deter insect attraction to host plants (Andow, 1991; Finch and Collier, 2000; Hooks and Johnson, 2003; Cai *et al*., 2007, 2010; Asare-Bediako *et al*., 2010; Hasheela *et al*., 2010; Ahmad and Ansari, 2013; Katsaruware and Dubiwa, 2014). Plants in the Allium family release strong volatiles (allyl-propenyl-disulphide) which reduce the attraction of phytophagous insects, alter host-finding behaviors, deter or stimulate some insects' olfactory organs and repel or attract predators (Nottingham, 1987; Renwick, 1999; Calvo-Gómez *et al*., 2004). Shallot belongs to the Alluim family and possesses similar properties. Aside that it is cheaper, safe and environmentally friendly. It also has economic value when used as intercrop and also maximizes the utilization of soil nutrients. However, little information is available on the appropriate planting time to accumulate the required amount of the alliaceous compound to sufficiently control cabbage pests. This is confirmed by Mandumbu *et al*. (2014), who reported that initial repellence of cabbage pests was slow when garlic was planted at the same time with cabbage due to little accumulation of the repellent compound.

Another promising pest management option lies in the evolution of agronomically cultivars that may resist the pest. Even a cultivar with partial resistance or tolerance can be utilized in the integrated pest management programmes as it will require less insecticidal protection. Several studies have surveyed cruciferous germplasm for plant resistance to Lepidoptera including the DBM and these cabbage cultivars vary in resistance to aphids and cartepillars (Shelton *et al*., 1988; Dickson *et al*., 1990; Talekar and Shelton, 1993). However, these cabbage varieties have not been empirically studied under local conditions in the study area.

This study sought to provide alternative solutions to farmer's problems in the Ketu South municipality and it demonstrated the potential of six pest management strategies to reduce infestation of key pests of two cabbage varieties while increasing populations of natural enemies of crop pests. The field work was carried out in three communities in the Ketu-South municipality, Volta region and this provided an opportunity for farmers to select and adopt better IPM strategies that are economical, environmentally safe, less hazardous as well as provide high economic returns and could contribute to boosting the vegetable (cabbage) growing industry and positively impact on vegetable farmers' livelihood and the physical health of consumers.

1.3 Objectives

1.3.1 Main objective

The main objective of this study was to evaluate the effects of six management strategies for the management of major insect pests of cabbage in the Ketu South municipality of the Volta region, Ghana.

1.3.1.1 Specific objectives

- To evaluate the effects of cabbage/shallot intercrop, two biopesticides and cabbage varieties in the management of major insect pests of cabbage in the Ketu-South municipality of the Volta region
- To evaluate the effects of cabbage/shallot intercrop, two biopesticides and cabbage varieties on the population of natural enemies in the Ketu-South municipality
- To determine the effect of cabbage/shallot intercrop and two biopesticides on the yield and quality of two varieties of cabbage in the Volta region

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Taxonomy, Origin and Geographical Distribution

Cabbage is an edible vegetable belonging to Kingdom: Plantae, Division: Magnoliophyta, Class: Magnoliopsida, Order: Brassicales, Family: Brassicaceae, Genus: Brassica and Species: *oleracea* variety *capitata*; hence, the scientific name *Brassica oleraceae* var. *capitata*. Other varieties of the same plant species include: cauliflower, brocolli, kale and brussel sprout. Cabbages and kale were the first of the Cole crops that were domesticated approximately 2,000 years ago mostly because of the important nutrients found in cabbage and its ability to thrive in various environmental conditions. Historically, modern head cabbage cultivars descended from wild non-heading brassicas originating from the Eastern Mediterranean and Asia Minor (Dickson and Wallace, 1986). The origin of cabbage is commonly accepted to be the North European countries and the Baltic Sea coast (Monteiro and Lunn, 1998), and the Mediterranean region (Vural *et al*., 2000), but now it is cultivated throughout the world including African countries (Obeng-Ofori, 1998).

Documentation of when cabbage farming started in Ghana is unknown (Cobblah *et al*., 2012), but it’s believed that cultivation started with the influx of the British, in the Gold Coast, in the 1940s (Sinnadurai, 1992). It was found to grow across the length and breadth of Ghana, except the Upper East region where interest in its cultivation was rather low (Timbilla and Nyarko, 2004).

2.2 World cabbage production

China is the biggest cabbage producer, with nearly 50% of the world's production (Figure 1). India, Russia and Korea all grow over 3 million tonnes and are followed by Ukraine, Japan and Indonesia (FAOSTATS, 2011).

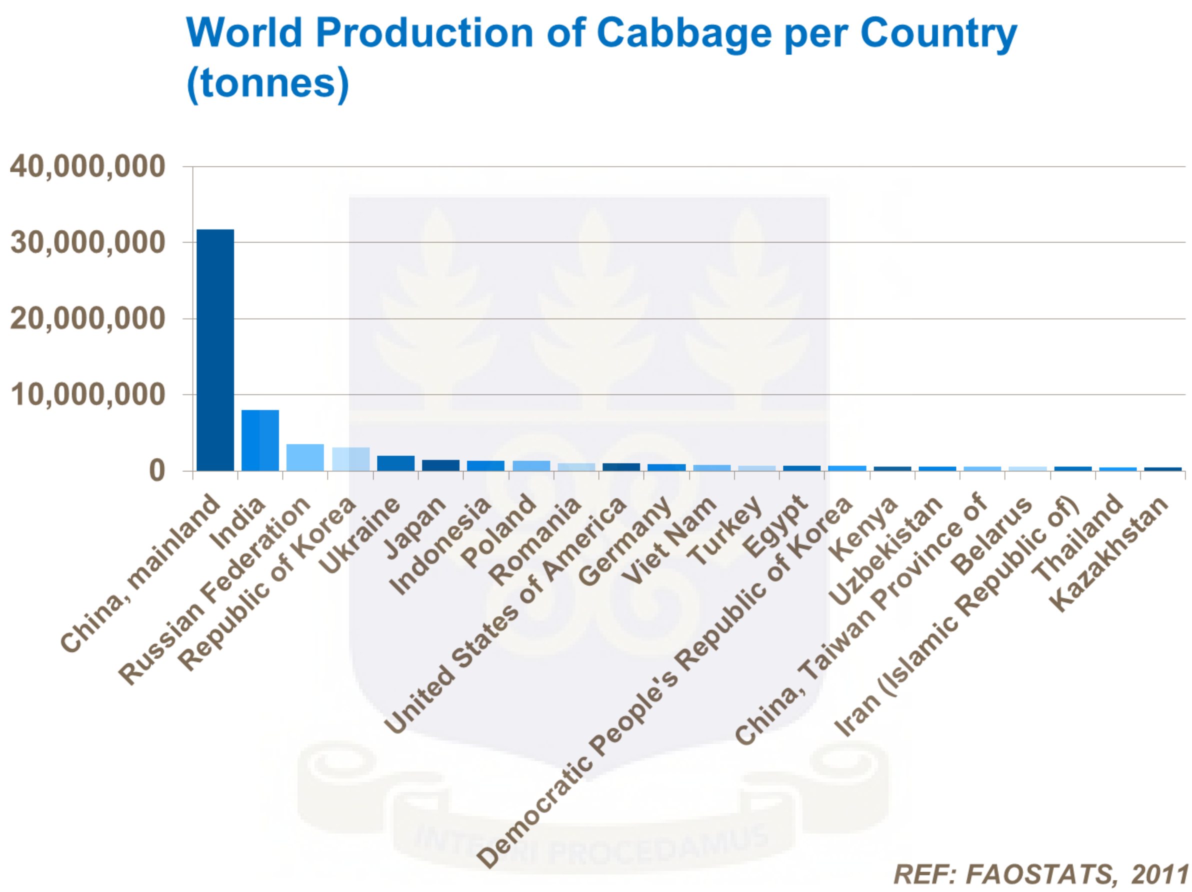


Figure 1: World cabbage production by country.

2.3 Cabbage Varieties

Over the years, many varieties of cabbage have been generated to suit consumer's taste and also to be able to withstand environmental stresses. These varieties differ in head size, shape, density, leaf texture and market maturity (Alabama Cooperative Extension Systems, 1999). In Ghana, the varieties that are adapted for cultivation are the Copenhagen Market, Drumhead, Suttons Tropical, Japanese Hybrid Cabbage, Golden Acre, Suttons Pride of the Market, KK Cross, White Oxylus and Marion (Obeng-Ofori *et al*., 2007; Cobblah *et al*., 2012). Other emerging varieties marketed in Ghana by AgriSeed, Adabraka in Accra, are Santa, Sahel, Fortune, Sultana and Supercross (Per. Comm. Ken O. Fening). Oxylus is susceptible to insect pest infestation (Per. Comm. Ken O. Fening) and it is the most preferred variety and transports and also stores well. Cabbage heads with tightly packed leaves leads to higher thrips populations; presumably because the insects are sheltered against predators (Voorrips, 2008). KK cross recorded least numbers of aphids in a study by Lal, 1989. Lack of variety diversity however, is a problem that needs to be addressed (Obeng- Ofori, 1998; Horna *et al*., 2006).

2.4 Agronomy

Cabbage is biennial but is grown as an annual crop (Amoako, 2010). Cabbage is made up of short unbranched stem with an adventitious root system. The 'head' which is the edible part of the cabbage plant, is basically a large vegetative terminal bud from series of expanded overlapping leaves which covers a small terminal bud (Sinnadurai, 1992; Rice *et al*., 1993) (Plate 1). The shape of the head may be round or pointed and the leaf colour and shape are variable (Rice *et al*., 1993; Andongma, 2010). Like other brassica, cabbage is grown from the seed, which can be done in nurseries and later transplanted, or directly in the field.

Plate 1: A healthy cabbage plant, variety; oxylus. Photo by Nkafu Therese, University of Ghana.

2.4.1 Cultivation requirements

Cabbage can grow on all soil types, but thrives better in sandy loam soil that is highly rich in organic matter (CPC, 2001a). It is known to respond well to organic manure and mineral fertilizer, particularly nitrogen and generally, needs a temperature of 15-25^{0}C for optimal growth, and is also sensitive to soil pH of 5.5 to 6.5 (Schmutterer, 1992; Hill, 1983). Small heads are produced when temperatures are high but varieties have been bred to produce large heads under such conditions. In the warm tropics like West Africa, the head cracks when mature and eventually deteriorate without flowering. 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). Close spacing of the seedlings in the nursery can cause the hypocotyls to elongate and 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. Immediately after sowing, the nursery should be shaded and the shade be removed after the seedlings have emerged to avoid distortion of seedling growth. 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). Cultural practices such as weeding is necessary for optimum yield.

2.5 Economic Importance of cabbage

Cabbage is easy to cultivate and its production can be a very profitable activity, with a quick return on investment (Norman, 1992; Mochiah, *et al*., 2011a). It is a high value crop with a great demand, especially from restaurants, hotels and a large section of the population in cities and urban areas (GhanaVeg, 2014) and its cultivation serves as a source of livelihood for the middle men and mostly unemployed youth (MoFA, 2011). It is used in several food preparations such as stews, soups and can sometimes be consumed raw, in salads, sandwiches and hamburgers (Asare-Bediako *et al.*, 2010; Baidoo *et al*., 2012).

Cabbage has high nutritive value, containing essential carbohydrates, proteins, vitamins and vital minerals (Table 1). It is an excellent source of vitamin C and betacarotene (vitamin A precursor). These anti-oxidants are considered helpful to combat the effects of free radicals in the human body (Timbilla and Nyarko, 2006). Cabbage production in Ghana provides an excellent source of employment for both the urban and rural dwellers, as it is grown in many rural areas as well as in the outskirts of towns and cities to be supplied fresh to the urban markets and for exports (Ghana Veg, 2014). Through exportation to other countries, cabbage production also serves as a source of foreign exchange for Ghana (Sinnadurai, 1992; GhanaVeg, 2014). Before being thought of as a food, cabbage was valued for medicinal purposes in treating gout, headaches, warts, appendicitis, boils, ulcers and diarrhoea (Hatfield, 2004). Cabbage juice was reportedly used as an antitoxin for poisonous mushrooms (Economic Research Service (ESR), 2002). Individuals eating more cruciferous vegetables have lower risk of colorectal, prostate and lung cancer compared to those who regularly eat other vegetables (Lin, 2008).

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

Nutrients	Nutrient Value	Percentages
Energy K cal – 27	27 Kcal	
Carbohydrate (g) - 4.6	4.6g	
Protein	1.8g	
Manganese	0.16mg	8%
Magnesium	12mg	3%
Sodium	0.18mg	2%
Carotene (mcg) - 1200	1200mcg	
Vitamin C (mg) - 12.4	36.6mg	44%
Niacin (mg) - 0.4	0.4mg	2%
Riboflavin (mcg) - 90	90mcg (0.040mg)	3%
Thiamine	60mcg	5%
Potassium	18mg	1%
Zinc	1microg	
Vitamine K	76microg	72%
Iron (mg) - 0.8	0.8mg	4%
Pantothenic acid	0.212mg	4%
Sugars	3.2g	
Dietary fibre	2.5g	
Folate (vitamine B9)	43microg	
Vitamine B6	0.124mg	10%
Fats (g) - 0.1	0.1g	
Moisture(g) - 91.9	91.9g	
Waste as purchased	15%	
Phosphorous (mg) - 44	26mg	4%
Calcium (mg) - 39	39mg	4%
Carotene-a	33 µg	--
Carotene-ß	42 µg	--
Lutein-zeaxanthin	30 µg	--

Source: Food and Agriculture Organization - Annual Report, 1992; USDA Nutrient data base

2.6 Constraints to cabbage production in Ghana

Despite the fact that cabbage is an important vegetable among peri-urban and urban dwellers in Ghana (Timbilla and Nyarko, 2004), its production is confronted with numerous constraints. 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). Attack by insect pests is prominent among these problems in Ghana. A wide spectrum of insect pests has been found to be associated with cabbage (Table 3), like any other cruciferous crop and this may be attributed to its nutritional and succulent nature (Chalfant *et al*., 1979; CPC, 2001b). According to CPC (2001a), cabbage has about 57 major pests and 28 minor ones including pathogens.

2.6.1 Insect pests of cabbage in Ghana

The pest complex of cabbage in Ghana is divided into two; major pests (cause significant damage of economic importance) and minor pests (does not cause any significant damage) (Shelton *et al.*, 1988; Fening *et al*., 2013, 2014a, b). (Table 2).

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

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

Source: Chalfant *et al*., 1979; Shelton *et al.*, 1988; Obeng-Ofori *et al*., 2007; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014a; Fening *et al*., 2016; Forchibe, 2016.

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

Insect pest	Origin and Distribution	Description and biology	Damage
Aphids; *Brevicoryne brassicae, Lipaphis erysimi, Myzus persicae*	origin: Europe distribution: worldwide	The adults are soft bodied and may be yellow, green, pink or brown. Winged adults are usually black. They give birth to live nymphs and can also lay eggs.	Both nymph and adults are sap feeders. They contaminate cabbage heads with their exuviae and honeydew which when attacked by a fungus, produces sooty mould, resulting in unmarketable heads. Also known to transmit several viral diseases to cabbage.
Diamondback Moth; *Plutella xylostella*	origin: Europe distribution: worldwide	Adults are greyish-brown with light brown band wings which gives a diamond-like pattern when folded. Eggs are oval and yellowish-white. Larvae are pale yellowish green with scattered erect hairs. Pupae are found in white open silky cocoon. Egg to adult, 16-23 days at 20^{0}C-25^{0}C.	Larvae feed on the under surface of the leaves resulting in a 'window effect'. They feed on the growing tip, resulting in multiple head formation. They also make irregular holes on the cabbage head.
Cabbage web worm; *Hellula undalis*	Origin: first identification in Italy Distribution: Worldwide	Adults are greyish-brown with yellowish-brown forewings and pale-dusky hind wings. Eggs are flattened and creamy. The larva is yellowish-grey with pinkish-brown stripes and a black head. The pupae are pale brown with dark dorsal strip enclosed in loose cocoon. Eggs hatch between 2-3 days. About 25 days to complete life cycle.	Larvae mines and feed on the growing tip of the cabbage plant, leading to multiple head formation. They also make webs and fold the foliage. Dirt and frass may later cover the webs.
Cabbage looper; *Trichoplusia ni*	origin: North America distribution: worldwide	Adults are grayish-brown with mottled brown forewings marked with small silvery spots. Eggs are round and greenish-white. Larvae are light green with three pairs of thickened prolegs at the abdomen and three pairs of slender legs at the head region. Pupae are green or brown enclosed in silky cocoon. Eggs hatch 3- 5days and caterpillar lasts for 14-21 days before pupating and pupa stage lasts for two weeks.	Larvae feed and make large irregular holes in leaves and cabbage heads. They also contaminate the heads with their frass making them unmarketable.
Cutworm;	origin: not	A generation lasts for about two	They usually attack the

Agrotis ipsilon	reported distribution: worldwide	months. Eggs hatch in 6-8 days and develop in 20-30 days	young plant in the nursery. They feed at night by cutting the young plants.
Cabbage white butterfly; *Pieris rapae*	Origin: Europe, Asia, Africa distribution: worldwide	Adults are white with white forewings and dull-yellow dusted hind wings. Eggs are usually pale yellow. Larvae has a series of yellow spots on body, velvety green in colour with short hairs on head and body and five pair of prolegs. Pupa varies in colour as it mimics with its environment. Eggs hatch in 8-10 days and larva undergo 5 instar stages and takes 15-18 days for pupa to emerge	Larvae chew and make holes in leaves and cabbage heads. Their feeding can contaminate plant.
Thrips tabaci	Origin: Mediterranean Distribution: Worldwide	Adults are pale yellowish to brownish, with four narrow, long wings fringed with long hairs. Immature thrips are smaller in size, wingless, and lighter in colour, but similar in shape to the adults. It was reported as an important cabbage pest since the late 1800s (Sirrine and Lowe, 1894).	Thrips feed on cabbages by puncturing and rasping the outer leaf tissue and sucking the sap as it exudes leaving leaves with a blistered, scarred, and bronzed appearance. The discolored areas coalesce to form large brownish, blister-like areas where many thrips have fed, resulting to unmarketable heads.

2.6.2 DIAMOND BACK MOTH, *Plutella xylostella* (LEPIDOPTERA: PLUTELLIDAE)

2.6.2.1 Morphology

Diamondback moth adult is a slender, small, grayish-brown moth with about 12-15 mm wingspan (Reid and Cuthbert, 1971). It has three pale triangular marking on the inner edge of each forewing that forms a diamond pattern when wings are folded from which it derives its name (Plate 2). The eggs are flattened and oval (Webb, 2002), pale green or yellow in colour, measuring 0.44 mm long and 0.26 mm wide, and are deposited in small groups of two to eight eggs or singly on leave surfaces (Hardy, 1938), or on other parts of the plant occasionally

(Sarfraz *et al*., 2005). The larvae vary in coloration from light brown at hatching through pale to dark green when fully matured. The body form of the larvae tapers at both ends, and a pair of prolegs protrudes from the posterior end, forming a distinctive "V". The larva curls and wriggles backward when disturbed, and may drop off the plant, where it can hang suspended on a silken thread (Sarfraz *et al*., 2009). Pupation occurs in a white, loose, silken cocoon about 9-12mm long. The pupal colour varies from pinkish-white to pinkish–yellow and changes to brown before adult emergence.

Plate 2: Adult, pupa, and larvae of the diamondback moth, *Plutella xylostella*

2.6.2.2 Origin and distribution

The diamondback moth may have its origin in Europe (Hardy, 1938), but Kfir (1998) speculated that it originated in South Africa and dispersed to Europe based on the large sexual and complex forms of its parasitoids and host plants found in South Africa. Similarly, Liu *et al*., (2000) stated that diamondback moth originated in East Asia. It is now present wherever its host plants exist and is considered to be the most universally distributed of all Lepidoptera. Depending on natural enemies, environmental conditions, migrations and overwintering populations, its infestation level varies from location to location and year to year. The cosmopolitan nature of *P. xylostella* is due primarily to the extensive cultivation of its host plant, Brassica spp., and its tendency to migrate long distances (Chu, 1986).

2.6.2.3 Taxonomic identification

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Plutellidae

Genus: *Plutella*

Species: *Plutella xylostella*

2.6.2.4 Biology and Ecology

2.6.2.4.1 Egg

The small yellowish eggs can be seen in the field with the use of a hand lens (Harcourt, 1961) (Plate 3). The incubation period of *P. xylostella* eggs is temperature dependent. The adult female can lay about 159 to 288 eggs in its life time (Harcourt, 1957; Ooi and Kelderman, 1979). Development time averages 5.6 days. Above 7.2°C (threshold temperature for egg development), Yamada and Kawasaki (1983) determined the total degree-days for egg development to be 52 and indicated that the hatching rate is negatively correlated with temperature.

2.6.2.4.2 Larva

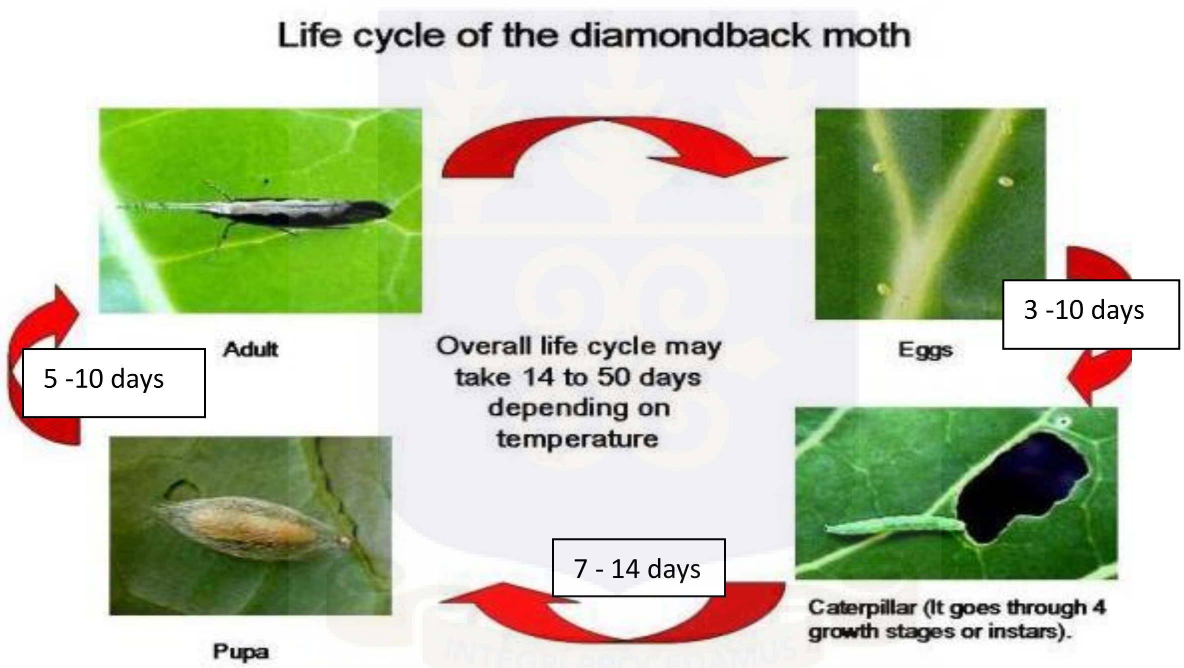
Diamondback moth has four instars. The first instar mines in the leaf tissue. The larvae molt under the leaf after they emerge from their mines at the conclusion of the first instar, and thereafter feed on the lower surface of the leaf voraciously. Fully grown caterpillars are 10-12 mm long and are green in colour (New South Wales Department of Agriculture, 1983) (Plate 3). The rate of development of larvae depends on temperature, and varies from 6 days in in warm climates such as Malaysia (OOi and Keldesman, 1979) to 15–21 days in cold regions such as Ontario (Harcourt, 1957). With a threshold temperature of 8.5°C, the total degree days for larval development is 161 (Yamada and Kawasaki, 1983).

2.6.2.4.3 Pupa

The pupae are encased in loosely woven cocoons fastened to the veins (Plate 3) on the under surface of leaves (Hill, 1983). Fully-grown larvae spin the cocoon, followed by 1 or 2 days of quiescence called the pre-pupal stage. The duration of the pupation varies from 4-15 days depending on temperature with optimum temperature of 27.5°C and minimum of 9.8°C (Yamada and Kawasaki, 1983). Adult emergence rate within the temperature range of 17.5-27.5°C, is 42-53.4% and emergence rate decreases above this temperature (Yamada and Kawasaki, 1983).

2.6.2.4.4 Adult

Adult moths are nocturnal, active at dusk and continue into the night (Harcourt, 1954). Mating starts on the emergence day, at dusk. Oviposition begins shortly after dusk (with peak oviposition between 19:00 and 20:00 hr where few eggs are laid after midnight) and continues for 10 days with number of eggs produced per female ranging from 159 to 288 (Harcourt, 1957; Ooi and Kelderman, 1979). Adult males and females live about 12 and 16 days, respectively. These moths can disperse only 13-35 m within a crop field since they are weak fliers (Mo JianHua *et al.*, 2003). They are, however, readily carried by the wind and can travel long distances, at 400-500 km per night (Chapman *et al.*, 2002). Temperature significantly affects adult survival, oviposition rates and generation time (Svapragasam and Heong, 1984), with a most favourable temperature of 30°C. Plate 3 shows a typica lifecycle of *P. xylostella*.



Source: A. M. Varela. Icipe

Plate 3: A typical Life cycle of diamondback moth.

2.6.2.5 Host status and specificity

The host plant range of *P. xylostella* is limited to Brassicaceae (mustard, broccoli, Brussels sprouts, cabbage, cauliflower, collard, kohlrabi Chinese cabbage, radish, kale, turnip, and watercress), which are characterized by having sulfur-containing compounds and glucosinolates.

Glucosinolates may be toxic to generalist insects, but a pest like DBM is known to rely on some of them for oviposition, host location and herbivory. Certain cardenolides, waxes, plant volatiles, glucosinolates as well as leaf morphology, host plant nutritional quality and leaf colour, or a combination of these factors, may trigger feeding and reproductive activities of DBM (Sarfraz *et al*., 2006). Cruciferous weeds serve as alternate hosts (Sarfraz *et al*., 2011), especially early in the season before cultivated crops are available. Some cruciferous weeds are important alternate 'bridge' hosts. For instance, the wind-borne moths can arrive in parts of the oilseed rape growing areas in Canada from the southern USA early enough that many of the rape crops will not have emerged yet (Canola Council of Canada, 2014). Non-cruciferous plants can also habour some populations. However, host plant shift from feeding on crucifers to feeding on non-crucifers may depend on geographical populations. For example, a Kenyan population of *P. xylostella* adapted to sugar snap peas (Löhr and Gathu, 2002) whereas a Canadian population, despite of multiple attempts, could not survive on peas in the laboratory.

2.6.2.6 Economic importance

Diamondback moth is one of the most economically important pests, causing economic damage in cultivated Brassica spp. throughout the world (Talekar and Shelton, 1993; You and Wei, 2007) and the destructive stage is its larvae (Chellaiah and Srinivasan, 1986). The pest first feed on leaves in its initial attack, and later on enters inside the curd thus causing qualitative and quantitative losses to this crop. It is characterized by intensive eating of the chlorophyll parts of the young and succulent leaves (Ooi, 1986) often causing a "window pane effect" (Francis *et al.*, 2005) and hence causes stunted growth by reducing the surface area for photosynthesis while rendering it unfit for consumption (Sanaverappanavar and Virktamath, 1997). The pest can infest all stages of plant growth causing defoliation, leaf curling and stunting of the plant. The larvae may also feed on the apical buds which can result in multiple head formation. Larval feeding can subject the crop to fungal and bacterial diseases such as soft rot (*Erwinia crotovora*). Boring of larvae into already formed heads is also another effect of their feeding which makes the heads unmarketable. Severe attacks may leave only the veins. The presence of larvae in florets can result in complete rejection of produce, even if the level of plant tissue removal is insignificant. In addition to crop losses, the management costs for controlling this pest annually were estimated to be more than US$1.0 billion globally (Grzywaez *et al.*, 2010) and later estimated to be between US $ 4 to 5 billion (Zalucki *et al*., 2012). Natural enemies such as the parasitic wasps, *Cotesi plutellae* (Hymenoptera: Braconidae) and *Diadegma. semiclausum* (Hymenoptera: Ichneumonidae) and predatory ants, *Camponotus* spp. (Hymenoptera: Formicidae) keep diamondback moth numbers in check (Youdeowei, 2002; Fening *et al*., 2011; 2013; 2014a). In Ghana, following serious outbreak of DBM in the Ashanti region, many farmers switched to the growing of other vegetables which were less susceptible to DBM (Horna *et al*., 2006) and the story is similar in other parts of the country (Per. Comm. K.O Fening).

2.6.3 APHIDS ON CABBAGE

Aphids are pear-shaped, delicate small insects with soft, fragile bodies belonging to the superfamily Aphidoidea (Blackman, 1974) (Plate 4). Adult aphids may be winged or wingless and range from 1.5 to 2.5 mm long, depending on the species. The nymphs (immature aphids), look like adults but are smaller and wingless. Aphids may be light green, black, yellow, pink, purple or mixed colors. There can be considerable colour variation even within a small colony of a single species (Blackman, 1974) and some are covered with waxy secretions (Blackman and Eastop, 1984). At least, three species of aphids are of economic importance to crucifer crops, including the turnip aphid, *Lipaphis erysimi* (Kaltenbach); green peach aphid, *Myzus persicae* (Sulzer) and cabbage aphid, *Brevicoryne brassicae* (Linnaeus), all of which have been reported in Ghana and South Africa (Daiber, 1971; Fening *et al*, 2013, 2014a; Fening *et al*., 2016; Forchibe 2016)

2.6.3.1 Cabbage Aphid, *Brevicoryne brassicae* (Homoptera: Aphididae)

2.6.3.1.1 Morphology

The genus of the cabbage aphid, *Brevicoryne* is derived from the Latin words “brevi” and “coryne” which loosely translates as “small pipes”. The cabbage aphids are small and pear-shaped insects with a length of 2.0 to 2.5 mm (Plate 4a), covered with a greyish waxy covering, with a thick and very short conicles (0.06-0.07) times the body length and 0.8-1.0 times the length of the cauda). They have a broad triangular cauda. Its shorter cronicles (with the exception of turnip aphids), triangular cauda with seven to eight curved hairs and the greyish waxy secretion that cover the aphids and the infested leaves, presents a distinguishing feature from other aphids that attack the same plant (Blackman and Eastop, 1984*;* Carter and Sorenson, 2013; Opfer and McGrath, 2013). The adult aphid may be winged (alate) or wingless (apterae) and unlike other aphids, they can attack the crop at any growth stage, causing significant yield losses (Elwakil and Mossler, 2013).

2.6.3.1.2 Origin and distribution

The cabbage aphid is known to have originated from Europe (Mau and Kissing, 1991), but have been extensively distributed as a result of its cruciferous host plants worldwide (Essig, 1947). It was first recorded in Oahu in 1907 but now found in all islands. It is one of the commonest species of insect to be found throughout the temperate and subtropical regions of the world. Severe damage on most plants in the family Brassicaceae have been reported in many areas including Canada, The Netherlands, South Africa, USA, India, China and Ghana (Carter and Sorensen, 2013; Amoabeng *et al.*, 2013; Fening *et al.*, 2013, 2014a).

2.6.3.1.3 Host status and specificity

The host range of the cabbage aphid is restricted to plants in the family Brassicaceae (Cruciferae), including both wild and cultivated cruciferous crops (Gabrys *et al.*, 1997), but its damage is more severe on cabbage and broccoli (Opfer and McGrath, 2013).

2.6.3.1.4 Biology and ecology

Aphids can reproduce two ways. In warm regions (Florida and Hawaii), females give birth to female nymphs without mating and an aphid colony consists only of females. In temperate regions, mating takes place and females lay eggs to produce males in response to low temperature or decrease in photoperiod (Blackman and Eastop, 1984). The overwintering stage of aphids is the egg stage. Up to 15 generations may be produced per cropping season and generations may be overlapping (Hines and Hutchison, 2013). Depending on temperature, the total life cycle duration ranges between 16 to 50 days but becomes shorter when temperatures are higher (Kessing and Mau, 1991).

2.6.3.1.4.1 Eggs

Eggs overwinter near the soil surface in plant debris in temperate regions, (Hines and Hutchison, 2013), whereas only female nymphs are produced directly without egg laying in warm climates (Kessing and Mau, 1991).

2.6.3.1.4. 2 Nymphs

In warm climates, the female gives birth to nymphs where eggs are not produced. The Nymphs are wingless and differ from adults by possessing a less developed caudae and siphunculi. The nymphal period varies from 7-10 days only. When a plant becomes overcrowded or when the quality of plants deteriorates, winged forms (alate) develop and start migrating to new hosts.

2.6.3.1.4.3 Adults

Adult cabbage aphids can be winged or wingless (Herrick and Huntgate, 1911), and have piercing-sucking mouthparts. Wingless adults are 1/10 inches long, oval-shaped and due to their waxy covering, they appear grayish-green or grayish-white (Hines and Hutchison, 2013; Natwick, 2009; Opfer and McGrath, 2013). Eight dark brown or black spots are located beneath the waxy coating on the upper abdominal surface and these spots increase in size toward the posterior end. Winged females lack the waxy covering of wingless females are smaller and

(Natwick, 2009) and the wings are short with prominent veins. The thorax and head are black to dark brown with dark-brown antennae. The wingless ones differ from winged aphids in that, the latter have a yellow abdomen with two dark spots on the dorsal anterior abdominal segments and the two spots merge into a dark band across the last abdominal segment (Kessing and Mau, 1991).

2.6.3.2 Green peach aphid, *Myzus persicae*

2.6.3.2.1 Morphology

In 1776, Sulzer initially described it as *Aphis persicae* (Plate 4b). Two forms exist which include the apterae or wingless types (which vary in colouration from whitish or pale yellowish green to mid-green, rose-pink or red, with a body length of 1.2-2.3 mm and possess a tapering, unswollen siphunculi) and the alatae or winged types (which have a black head and thorax, yellowish green abdomen with a body length of 1.8 to 2.1 mm and the immature are often pink or red) (Blackman and Eastop, 1984). The antennae and cornicles of the green peach aphid are the same color as the body, but slightly darker at the end. It differs from other aphid species found on crucifers in that the antennal tubercles are prominent and pointed inward, and the cornicles are swollen near the base and are longer than the cauda. The nymphs are smaller but similar to adults in shape and colour.

2.6.3.2.2 Origin and distribution

Myzus persicae is of East Asian origin probably like its primary host plant (*Prunus persica*), but is now world-wide except in areas of temperature or humidity extremes (CIE, 1979).

2.6.3.2.3 Host status and specificity

It has over 400 host plant species which are in over 40 different families, including Convolvulaceae, Brassicaceae, Cyperaceae, Solanaceae, Leguminosae, Poaceae, Chenopodiaceae, Cucurbitaceae, Compositae and Umbelliferae. It has been recorded on all continents where crops are grown (Blackman and Eastop, 2000).

2.6.3.2.4 Biology and ecology

Myzus persicae is heteroecious holocyclic (host alternating, with sexual reproduction during part of life-cycle) between summer host plants and *Prunus* (usually peach), but anholocyclic on secondary (summer) hosts in many parts of the world where peach is absent, and where a mild climate permits active stages to survive throughout the winter (Blackman, 1974). In the tropics and sub-tropics, it is anholocyclic with exceptions: for example, Ghosh and Verma (1990) reported apterous oviparous females of *M. persicae* for the first time from India, collected on *Prunus persica*. In the warmer climates, it reproduces asexually and they may be twenty generations a year. As the weather cools, aphids mate and lay their tiny (0.6 mm x 0.3 mm) oval eggs in crevices of the bark of *Prunus* trees.

2.6.3.3 The mustard aphid, *Lipaphis erysimi* (Homoptera: Aphididae)

2.6.3.3.1 Morphology

Apterae are dirty green, yellowish green, or brownish with a body length of 1.5-2.3 mm. They are varying shades of green and have slightly darker spots on the dorsal surface of the abdominal segments in front of the cornicles. Winged females have dusky green abdomens with dark lateral stripes (Blackman and Eastop, 1984). The antennae are also dark, except at the base (Deshpande, 1937). These aphids have a slightly visible thin layer of white, waxy secretions (much less than the cabbage aphid) (Plate 4c). Their major distinguishing characteristics from other aphids are the frontal tubercles do not converge; the cornicles are not dark and are longer than the cauda; the cauda is tongue-shaped; and colonies have a thin layer of white, waxy secretion (Blackman and Eastop, 1984).

2.6.3.3.2 Origin and distribution

The turnip or mustard aphid is distributed worldwide (Blackman and Eastop, 1984). Records in the literature report this aphid has been on Maui since 1987.

2.6.3.3.3 Host status and specificity

This pest is widely distributed on all Brassica crops worldwide (Alavo and Abagli, 2011).

2.6.3.3.4 Biology and ecology

This aphid has two modes of reproduction: fertilization of females by males resulting in the production of eggs (sexual reproduction), and the birthing of live female nymphs by adult females without fertilization by males (parthenogenesis). Reproduction through parthenogenesis is more common as males are very rare and females are almost exclusively viviparous throughout the year and males have only been observed in the cooler months (Kawada and Murai, 1979). Its longevity depends crucially on temperature.

a) *B. brassicae* b) *Myzus persicae* c) *Lipaphis erysimi*

Plate 4: Pictures of different species of aphids. Photo by Forchibe Ethelyn Echep.

2.6.3.4 Economic importance of aphids

Aphids are destructive pest in all areas where cabbage is grown (Bhatia and Verma, 1994; Dattu and Dattu, 1995), causing severe losses in cruciferous crop production, by reduction of yield and marketability (Liu *et al*., 1994; Costello and Altieri, 1995). Generally, aphids have piercing and sucking mouthparts used for sucking sap from their host plants. The damage caused by aphids to cruciferous crops, can be direct or indirect damage. Direct damage can be caused by both adults and nymphs; with their mouthparts, they attach to their host plant tissues and suck sap from them, depriving them of nutrients. This leads to weak, wrinkled leaves that are cupped outward and inward, resulting in a deformed plant with lower yields (Hughes, 1963; Mochiah *et al.*, 2011a). The wrinkled leaves later become wilted, distorted or yellowish when the population of the aphids increases. Their feeding also leads to stunted growth, and eventually death of the plant, and sometimes unmarketable heads (Behdad, 1982; Griffin and Williamson, 2012).

Indirect damage from aphid feeding results from the excreta (honeydew) that supports the growth of sooty mould (Hughes, 1963) and also transmission of viral diseases (Blackman and Eastop, 2000; Parker *et al*., 2003)

2.7 Management of cabbage pests

Until now several control methods have been employed to manage cabbage pests.

2.7.1 Cultural control

Before the advent of synthetic insecticides, insect pest control was dependent on cultural control methods. This is considered important to suppress pest populations in IPM programmes (Brader, 1979). Recently, because of failure of insecticides to control most insect pest on cabbage (Ninsin, 1997; Shelton *et al*., 1993) and its side effects (Devotto *et al*., 2007; Asante, 2009; Fernandez *et al*., 2010; Fening *et al*., 2013, 2014a), there has been a keen interest in cultural control in commercial cabbage production. Below are some cultural control practices used for pest management.

2.7.1.1 Farm sanitation

Pest infestation on cabbage fields can be greatly reduced by practicing general farm sanitation and clean cultivation. To prevent the spread of pests to other crops, the fields should be ploughed after harvest (Griffin and Williamson, 2012). Getting rid of alternate host plants like cruciferous weeds or mustards from the field or surrounding areas is very important (Natwick, 2009). Destroying plant debris at the end of the season can help kill overwintering eggs in temperate climates (Hines and Hutchison, 2013). Replanting on aphid-infested crop land will lead to carry-over of pests and therefore, not advisable (Razaq *et al*., 2012).

2.7.1.2 Crop rotation

This is a method of organic farming in which different crops are planted on a piece of land every farming season. Crop rotation with non-host crops is also beneficial in insect pest control (Kessing and Mau, 1991), and is the first general agronomic rule to avoid soil-pest. This method of farming reduces build-up of pest, and improves soil fertility especially when leguminous crops are incorporated in the cycle. Concerning aerial pests, some insects use different host plants as food in their larval stages from the plants they eat in their adult stage (Schoonhoven *et al*., 2005). Thus, a plant believed to be a non-host for an insect pest at one stage may turn out to be a host plant at another stage, making the choice of the crop very crucial.

2.7.1.3 Intercropping

Intercropping is a method of farming that involves the cultivation of two or more crops simultaneously on the same field (Björkman, 2007). Multiple cropping is the world's oldest cropping system (Brady, 1986) and has its roots in the history of civilization as we know today (Francis, 1986). Food was produced in mixed culture long before the modern systems of monoculture came into existence, where several different species were harvested from a given land area (Brandy, 1986). The percentage of cropped lands in the tropics used for intercropping varied from low (17% in India) to high (94% in Malawi) (Edje, 1979). Intercropping is a better technology to increase crop production due to its substantial yield advantage than sole cropping

(Awal *et al*., 2006), where there is population explosion by pests as a result of higher concentration of host plants (Abate *et al*., 2000). Intercropping practices have been kept aside for several reasons due to the development of modern agriculture. However, despite the resurgence of interest in intercropping (Francis, 1986), it seems currently, that it is only practised by a few current farmers. There are two main approaches to achieve a design leading to a beneficial intercrop. The first is to associate complementarity in order to reduce the competition and the second is to seek for mutualism in the crop association.

2.7.1.3.1 Mutualistic crops to increase facilitation

The facilitative production principle or "facilitation" is the ecological process when "one species provides some sort of benefits for another species" (Vandermeer, 1989). An example is the decrease in pests and diseases pressure. Because intercropping promotes crop diversity, it can lead to a decrease in pests and diseases pressure and Vandermeer (1989) has defined some hypotheses to explain the decrease which include the following:

2.7.1.3.1.1 The enemy hypothesis

The intercrop attracts more beneficial predators and parasites than the monocultures, and offers a higher availability of habitats or food sources, thus reducing the pest population through predation or parasitism.

2.7.1.3.1.2 The trap-crop hypothesis

In this case, a second species attracts a pest that would normally be detrimental to the principal crop in the vicinity of a principal crop. This is mainly applicable to generalist herbivores.

2.7.1.3.1.3 The suppression hypothesis

Some plants exude chemicals from roots or aerial parts that repel or suppress pests/diseases and protect neighbouring plants. "When two plants grow near one another, basic physiological principles suggest that they will almost compete, whether or not facilitation is operative (Vandermeer, 1989)". FAO (1990) reported a reduction in damage caused by insect pest when crops like white mustard (*Brassica hirta*) and rape (*Brassica juncea*), were used as trap crops in cabbage. Mochiah *et al*. (2011a) in a related work in Ghana showed that tomatoes intercropped with cabbages were effective in reducing the number of insect pests on cabbage whilst Vostrikov (1915) recorded a reduced damage to cabbage by several pests when cabbages were intercropped with tomatoes. Similar studies by Srinivasan and Krishna (1992) and Asare-Bediako *et al*. (2010) concluded that cabbage-onion intercrop was as effective in reducing DBM numbers as cabbage treated fortnightly with chlorpyrifos (a synthetic insecticide). Diverse planting of cabbage with onion was effective against key pests such as the diamondback moth and the cabbage webworm (Oseifuah, 2015). In a similar study, however, Baidoo *et al*. (2012) did not record a significant reduction of *P. xylostella* numbers in an onion-cabbage intercrop. Only limited successes with regards to intercropping have been documented in India (Chelliah and Srinivasan, 1986), the Philippines (Magallona, 1986) and Taiwan (AVRDC, 1987). More so, none of the 54 intercropped plants tested in Taiwan had any significant impact on the pest population on cabbage. A given pest may show variable responses over space and time (Risch *et al*., 1983) and Helenius (1998) stated that intercropping does not necessarily guarantee the reduction of the impact of the pests and in some cases, results in loss of weight in vegetable plantings (Theunissen *et al.*, 1995).

2.7.1.4 Host plant resistance

The use of host plant resistance as an insect pest management tactic is well established (Painter, 1951). Plants respond to herbivore attack through a dynamic and intricate defense system that includes structural barriers, toxic chemicals, and attraction of natural enemies of the target pests (Hanley *et al*., 2007; Howe and Jander, 2008). The use of resistant cultivars, either alone or in combination with other methods, provides crop protection that is biologically, ecologically, economically, and socially feasible (Teetes, 1985). Resistant cultivars are nonpolluting to our environment and may be grown at no extra expense to the farmer. Cruciferous crops differ in their susceptibility to attack by insect pests. Mustard, turnip, and kohlrabi are among the more resistant crucifers. Increased waxiness in brassicas decreased aphid colonization, mainly due to a non-preference resistance mechanism (Stoner, 1992). Jahan *et al*. (2013) concluded that the cauliflower cultivar ‘Smilla’ is a good choice because it affects adult reproductive parameters of aphids. Dickson *et al*. (1986) reported the release of four cabbage breeding lines possessing resistance to *P. xylostella*. Previous research has shown variable susceptibility in cabbages (*Brassica oleracea capitata* group) to damage by *P. xylostella*, and a major component of this resistance has been associated with a glossy leaf-wax trait (Stoner, 1990; Eigenbrode *et al*., 1990; Eigenbrode *et al*., 1991). Generally, *P. xylostella*-resistant cabbage cultivars are not commercially available. The choice of cultivar could, however, reduce key pest populations and damage.

2.7.2 Use of various Traps

Different trapping techniques exist and are used for monitoring the populations of different pest species. The adults of diamondback are attracted to light traps and adult males are attracted to sex pheromone. A number of sex pheromones are available for the management of lepidopteran pests of vegetables, including cabbage (Badenez-perez *et al.*, 2004). The diamondback pheromone consists of three chemicals: (Z)-11-hexadecenyl acetate, (Z)-11-hexadecenal, and (Z)-11-hexadecenyl alcohol (Chow *et al*., 1978) and this has been exploited particularly when used in combination with augmentation or conservation of natural enemies. Pheromones are chemical substances (messengers) that are released by species specific insects for communication (Vet and Dicke, 1992). 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. In Japan, mating disruption has been achieved in the field using high pheromone concentrations (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 with promising results in multi-location trials (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* and two parasitoids *(Diaretiella rapae* (Hymenoptera: Braconidae) and *Praon volucre (*Hymenoptera: Braconidae). The yellow sticky traps can also be used to monitor DBM populations in the field (Sivapragasam and Saito, 1986). Therefore, use of trapping technique is a promising method for control of cabbage pests.

2.7.3 Chemical control

Production of healthy and damage free vegetables, especially cabbage for the wealthy urban population and the international market is of outmost concern, and an important consideration in all farming practices, especially plant protection (Talekar and Shelton, 1993). To achieve this, most farmers use insecticides because they believe it gives rapid results (Ntow *et al*., 2006; Essumang *et al*., 2008; Owusu-Boateng and Amuzu, 2013). An estimated one-third of the world's food supply would be lost each year if crop protection chemicals were not used and this is enough to feed about two billion people (William, 1992). Chemicals thus play a great role in agriculture.

2.7.3.1 Synthetic insecticides

In Ghana, several synthetic insecticides are used against cabbage pests (Table 4) (Odhiambo, 2005; Amoako, 2010), belonging to three different classes (organophosphates, carbamates and pyrethroids) (Ntow *et al*., 2006; Andongma, 2010). A study conducted in Southern Ghana confirmed over dependence by farmers on synthetic pesticides (Atieno *et al*., 2014). Karishniah and Mohan (1983) reported that Chlorpyrifos gave effective control and suppressed the population of mustard aphid. Jansson *et al.* (2012) reported that Emamectin benzoate was effective against lepidopterous pests, with a minimal effect on the beneficial insects. Lambda cyhalothrin 2.5EC is highly active against a wide range of species of Lepidoptera, Hemiptera, Diptera and Coleoptera (WHO, 1990). Despite the fact that some successes have been achieved with chemical control, over the years, synthetic pesticides have been realized to have negative effects which includes: destruction of non-target organisms such as beneficial insects (pollinators and natural enemies); contamination of farm produce with insecticide residues; exposure of users to risks of chemical poisoning; environmental contamination and development of insecticide resistance (Obeng-Ofori *et al*., 2002; Timbilla and Nyarko, 2004; Ntow *et al*., 2006; Fening *et al*., 2011, 2013, 2014; Amoabeng *et al*., 2017). Fernandez *et al*. (2010) and Devotto *et al*. (2007) reported that organophosphates and pyrethroids are broad spectrum insecticides, and are known to be highly toxic to predators. For example, Chlorpyrifos 20% EC, was found to be highly toxic to the maggots of the hoverfly, *Ischiodon scutellaris* (Boopathi and Pathak, 2011). Ninsin (1997) noted that various synthetic insecticides applied on cabbage had adverse effects on non-target insects and other beneficial organisms in Ghana. Fening *et al*. (2013) reported adverse effects on natural enemies by lambda-cyhalothrin, leading to continuous build-up of pests on cabbage. All these major setbacks for synthetic insecticides calls for alternative approaches to managing vegetables to obtain sustainable control (Ntow *et al*., 2006; Coulibaly *et al*., 2007; Fening *et al*., 2014a).

Table 4: 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
Deltapaz 2.5 EC	Deltamethrin	Pyrethroid	7
Cypercal 50 EC	Cypermethrin	Pyrethroid	7
Karate 5 EC	Lambda cyhalothrin	Pyrethroid	7
Pyrical 480 EC	Chloropyrifos Ethyl	Organophosphate	7
Orthene 750 sp	Acephate	Organophosphate	4
Pawa 2.5 EC	Lambda cyhalothrin	Pyrethroid	4
Cymethoate	Cymethoate	Organophosphate	7
Dimethoate	Dimethoate	Organophosphate	15
Sumithion	Fenitrothion	Organophosphate	14
Dursban 4 E	Chlopyrifos	Organophosphate	15
Thionex 35 EC	Endosulphan	Organophosphate	14
Cymthox	Fenvalerate	Pyrethroid	7
Thiodan	Endosulphan	Organochlorine	14

Mektin 1.5 EC	Abamectin	Bio- insecticide	3
Confidor 200sl	Imidacloprid	Neonicotinoid	7
Diazol 50 EC	Diazion	Organophosphate	7
Wrecko 2.5 EC	Lambda cyhalothrin	Pyrethroid	15
Endocel	Endosulphan	Organochlorine	15
Attack	Emamectin benzoate	Bio- insecticide	7
Rimon 10 EC	Novaluron	IGRs	7
Akate Master	Bifenthrin	Pyrethroid	7

Source: Amoako, 2010.

2. 7.3.2 Insect growth regulators

Insect growth regulators disrupt the normal growth and development of immature insects and slowly kill the insects over a period of few days (Ohbayashi *et al*., 1992). These insecticides are used in an integrated pest management system and are comparatively safer to beneficial insects and environment. Novaluron for example acts as an insecticide mainly by ingestion but also 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. Rimon® is an example of IGR used in Ghana (Odhiambo, 2005). Insect growth regulators and pathogens therefore, 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).

2.7.4 Microbial/ biopesticides

Biopesticides or microbial controls consist of *Bacillus thuringiensis*, insect - consuming fungi such as *Beauveria bassiana, Metarhizium anisopliae*, and viruses such as Baculoviruses (Furlong *et al*., 2004). *B. thuringiensis* is a naturally occurring bacterium that produces a toxin that causes paralysis of a caterpillar's digestive tract (Guerena, 2006). A caterpillar will stop feeding but may continue to live for some hours after ingestion, consequently, causes death by starvation, septicemia and/or osmotic shock within 24 to 48 hours (Rowell and Bessin, 2005). *B. thuringiensis* strains are available in a number of commercial products, under various trade names. *B. thuringiensis* degrades rapidly in sunlight and requires careful timing or repeated applications for (Guerena, 2006), for better performance. *B. thuringiensis* 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). More so, microbial pathogens, including those belonging to the family Baculoviridae are considered a more sustainable option in the management of insect pests. A granulovirus of *S. litura* was reported to infect all stages of the caterpillar in India (Battu *et al*., 1971), though the killing process is a slow one (Subramanian *et al*., 2005). McEwen and Hervey (1958, 1959) showed that a polyhedrosis virus had possibilities for control of the cabbage looper. Current concepts in baculovirus application are not averse to the joint use of the pathogen and insecticides. Synergism has been reported when mixtures of baculovirus and insecticides are targeted against larval stages under laboratory conditions (Rabindra and Jayaraj, 1994) and in the field (Rabindra *et al*., 1992). They are equally able to break the resistance to insecticides which give them an added advantage (Huang and Dai, 1991).

Bypel 1® is one of such commercial insecticide that is derived from a mixture of *Bacillus thuringiensis* and *pieris rapae* granulosis virus. It is a safer and biodegradable insecticide and has a known insecticidal property that could be feasible and effective for insect pest. Huang and Dai (1991) and Mallioux and Bellonick (1995) found synergistic action of *Pieris rapae* granulosis virus with insecticides like fenvalerate, dimehypo, acephate, trichlorfon, and carbaryl. Li and Sengonca (2003) observed that GCSC-BtA (Germany-China Scientific Cooperation - *Bacillus thuringiensis* - Abamectin) biocide showed high efficacy in reducing abundance of cabbage pests with very low harmfulness to their natural enemies whilst Paul *et al*. (1997) evaluated commercial formulation of *B. thuringiensis* and cabbage cultivar resistance against diamondback moth and concluded that 'tropicana' cabbage cultivar and products containing effective strains of *B. thuringiensis* are effective against *P. xylostella* in Jamaica. Several studies on biopesticides (Navon, 2000; Owusu-Ansah *et al*., 2001; Obeng-Ofori and Ankrah, 2002), clearly indicate no effect of biopesticides on natural enemies of insect pest.

2.7.5 Botanicals

Botanicals are plant extracts that are toxic to insects through contact, respiratory or stomach poison due to certain compounds and secondary metabolites which they contain (Kareru *et al*., 2013). Extracts of some plant families (Meliaceae, Rutaceae, Asteraceae, Labiatae, Piperaceae and Annonaceae (Jacobson, 1989; Isman, 1995) and essential oils have been used to protect crops against attack for ages because they have been prove to be toxic to some economic important insect pests (Isman, 2002; Belmain and Stevenson, 2001; Koul, 2004; Regnault-Roger *et al*., 2005; Isman, 2008). They are capable of managing insecticide-resistant pests of many crops (Amoabeng *et al*., 2013), and are biodegrable with greater selectivity. Due to the negative impact of pesticides, much effort has been devoted to find alternative control measures for most pests, such as botanical insecticides, antifeedants and insect growth regulators with non-neurotoxic modes of action. Botanicals are often regarded as safe to humans, animals and the environment because of their specificity and non-persistent nature (Charleston *et al*., 2006; Dubey *et al*., 2011). Srivastava and Guleria (2003) reported thirty-four plants with insecticidal activity against *L. erysimi*. Table 5 shows some local plants with insecticidal properties.

Table 5: Some local plants with insecticidal properties

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

Source: Mureithi, 2008; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014a, b.

2.7.5.1 The neem plant (*Azadirachta indica* A. Juss) and its importance in pest control.

The neem tree, *Azadirachta indica* A. Juss belongs to the family Meliaceae (Plate 5). Neem has long been recognized for its natural insecticidal properties (Saxena *et al*., 1988). The active ingredient azadirachtin which is a tetranortriterpenoid was isolated from the seed kernels of the indian neem tree *Azadirachta indica A.* Juss (Meliaceae) by David Morgan (Butterworth and Morgan, 1968) and its full structural determination was completed some 17 years later concurrently in the laboratories of Steven Ley, W Kraus and K Nakanishi (Kraus *et al*, 1987). Azadirachtin is found in three species of trees; *Azadirachta indica* (Rutales: Meliaceae), *A. excelsa*, and *A. siamensis.* It is now well established that azadirachtin is a potent anti-feedant and has a strong disrupting effect on growth and development of several insect species (Schmutterer, 1990; Mordue and Blackwell, 1993). Heinrich Schmutterer in 1952 recorded desert locusts (*Schistocerca gregaria* (Forskal)) refusing to feed on neem. Azadirachtin is a biopesticide, and one of the most widely used botanical insect growth regulators. It is biodegradable (it degrades within 100 hours when exposed to light and water) and shows very low toxicity to mammals (the LD50 in rats is > 5000 mg/kg (Yu, 2008) making it practically non-toxic. Because of its structural resemblance to the natural insect molting hormone ecdysone, azadirachtin interrupts molting, metamorphosis, and development of the female reproductive system. Isman (2006) recorded azadirachtin as a potent insect growth regulator and feeding deterrent, with very low mammalian toxicity and environmental persistence.

Due to its unique mode of action, this biochemical insect growth regulator has played an important role in integrated pest management systems and as an effective resistance management tool. Schmutterer (1990) suggested that azadirachtin modifies the programmes of insects by influencing hormonal systems, especially that of ecdysone, to prevent both ecdysis and apolysis, and can cause death before or during molting. Several studies have been conducted on neem in Ghana. Lidet *et al*. (2009) and Sow *et al*. (2013) reported improved cabbage yield when neem was used against insect pest. Work by Obeng-Ofori (2008) using crude seed extracts of neem was effective against insect pests of tomato, cabbage, cucumber, okra, pepper and garden eggs. Eziah (1999) reported the efficacy of neem seed extract against *Thrips palmi* on aubergine in the University farm, Legon. Use of *A. indica* seeds and *Lanthana camara* leaf extracts in cabbage fields, increased yield by 37.05% and 25.80%, respectively, with a significant reduction in the number of pests (Baidoo and Adam, 2012). Dzomeku *et al*. (2011) reported that neem seed extract was highly effective in protecting cabbage plants against insect pests leading to high yield quality compared to Karate (Lambda cyhalothrin) and water whilst Rando *et al.* 2011; Kibrom *et al*. 2012 and Forchibe (2016) noted that neem seed extract effectively managed cabbage aphids leading to higher yields and more marketable heads than their synthetic counterparts (chlorpyrifos and lambda-cyhalothrin). Similar work by Ezena *et al*. (2016) demonstrated the potential of neem seed extract against major pests of cabbage while maintaining ecological balance with their natural enemies. Appiagyei (2010) reported that whiteflies were more susceptible to neem extracts than to karate (lambda-cyhalothrin). A similar study by Prasannakumar *et al*. (2014) recorded effective control of *H. undalis* and aphids when cabbages were treated with neem seed powder extract. Lepidopteran pests of eggplant have been successfully managed by aqueous neem seed extract (Afreh-Nuamah, 1996). Therefore, botanical insecticides can provide realistic alternatives to chemical insecticides because of their safety to the user and the wider ecosystem (Rechcigl and Rechcigl, 2000; Buss and Park-Brown, 2002).

Plate 5: Fresh neem seeds.

2.7.6 Biological control

Biological control involves the use of natural enemies; microbials, predators and parasitoids to control insect pests. Generally, natural enemy populations are often numerous enough to keep pest infestations below economic levels (Pedigo, 1999; Mandal and Patnaik, 2008). Protecting the habitat that will foster the population and survival of natural enemies can help reduce the need for pesticides (Natwick, 2009).

2.7.6.1 Ladybird beetles (Coleoptera: Coccinellidae)

Ladybird beetles are insect species commonly found everywhere on the globe. About 6000 species exist worldwide (Frank and Mizell, 2014). They are oval and measure about 1-10mm (Frank and Mizell, 2014). The adult females are larger than the males. Adults are characteristically known for their bright colours which range from various shades of orange, red, brown and black. They may have black spots or bands. The larvae are flattened and elongated and are usually brightly coloured and may have bands on body. Ladybirds undergo complete metamorphosis, where the adult female lays elongated and ovoidal eggs among aphid populations. It hatches between 3-10 days depending on temperatures. The eggs hatch into 'alligator' shaped larvae that are elongated and pointed at the rear ends. The larva lives and grows through 4 larval instar stages (Perdikis *et al*., 2008; Frank and Mizell, 2014) which last for about 1 month before becoming pupa and the pupal stage lasts for 15 days. The pupa is dark and round and is found attached to surfaces by their hind legs. The pupa then emerges into a distinctly colourful adult (University of Illinois, 2008). The adult and larvae are both predators. Plate 6 shows a picture of the adult and larval stage of a ladybird species. The adults possess chewing mouthparts whilst the larvae have piercing and sucking mouthparts (Frank and Mizell, 2014). They mainly feed on soft bodied insects like the aphids, mealybugs, whiteflies and even on eggs laid by insect pests. They are major predators of aphids, because it is needed for egg production (Frank and Mizell, 2014). The species of ladybird beetles that have been found attacking cabbage aphids in Ghana include *Cheilomenes lunata*, *C. propinqua vicina* and *Coccinella* spp. (Amoabeng *et al*., 2013; Fening *et al*., 2011, 2013, 2014a)

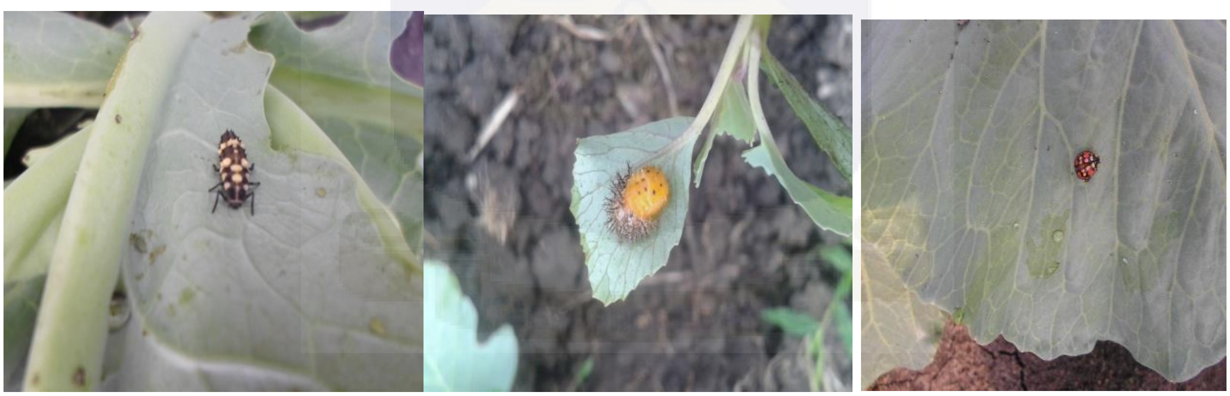


Plate 6: Ladybird beetle, *Cheilomenes* sp. (larva, pupa and adult).

2.7.6.2 Spiders (Araneae)

Spiders are arthropods belonging to the class Arachnida. They differ from insects by the possession of four pairs of legs and two body divisions (Plate 7). Spiders are all predaceous and they kill their prey by injection of venom. Spiders are the largest number of invertebrate predators in terrestrial habitats (Quan *et al*., 2011). They are important predators of DBM on cabbage in the field (Zhao, 1995; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014a). In a study by Hooks *et al*. (2007), it was observed that spiders were able to reduce the numbers of *P. rapae*, by feeding on the eggs. A reduction of *T. ni* eggs was also observed when spider numbers were increased. There could be hunting or webbing type of spider as an adaptation to the catching of its prey (Dippenaar-Schoeman *et al*., 2013; Ghoneim, 2014).

Plate 7: Some spiders (predators) on cabbage.

2.7.6.3 Hoverflies (Diptera: Syrphidae)

Hoverflies are small to medium-sized flies that can hover motionless in the air. They are also known as Syrphid flies or flower flies. The adults are brightly coloured often with black and yellow stripes along the abdomen and have bands on their body. The adults mimic bees or wasps but are stingless and the mimicry is a way to protect itself from enemies such as birds. The proboscis is short, therefore Syrphid flies tend to visit smaller flowers with short nectar tubes in sunny places. The larvae are important in controlling cabbage aphids, *B. brassicae*, *L. erysimi* and *M. persicae* (Plate 8) and other pests. *Paragus borbonicus* (Diptera: Syrphidae) is a species of hoverfly that has been commonly found on cabbage at Kpong in Ghana (Forchibe, 2016).

Plate 8: Hoverfly larvae and their prey, aphids on cabbage.

2.7.6.4 Parasitoids and hyper parasitoids (Hymenoptera)

Parasitoids are insects that lay eggs in or on the eggs or body of their host (Ortiz, 2011). The eggs then hatch into immatures that are parasitic and exploit the host body for food. Under natural conditions, different pests keep their populations at check using various natural enemies. The cabbage aphid and DBM are associated with a number of parasitoids. Reported parasitoids are from the Braconidae family (Duchorskiené *et al*., 2010; Cobblah *et al*., 2012). Two of them are *Cotesia plutellae* (Kurdjumov) on DBM and *Diaeretiella rapae* (M'Intosh) on aphids (Oseifuah, 2015; Ezena, 2015; Forchibe, 2016). On releasing *D. rapae* into a broccoli field after seven weeks, percent parasitism of aphids were 6.7% and 1.4% in the treated and control plots, respectively (Zhang and Hassan, 2003). Cobblah *et al*. (2012) recorded a significant higher parasitism rate (68.6 ± 12.9%) and the least parasitism of (9.9 ±7.1%) of DBM by *C. plutellae* in the major and minor rainy seasons, respectively. However, Fening *et al*. (2014b) in a study using homemade extracts of pepper to manage insect pests on cabbage and French beans in two different agro ecological zones did not observe any significant differences in the percent parasitism of DBM by *C. plutellae* among the treatments at the two locations, where the parasitism ranged from 53.81 ± 9.27% to 73.01 ±20.27%. More so, Hu *et al*. (1997) considered this parasitoid inefficient because of its poor searching ability when pest populations were low. An important Ichneumonid larval parasitoid of DBM is *Diadegma semiclausum*.

Apart from the main parasitoids, hyper parasitoids are effective in controlling aphid and DBM populations. In a work by Nematollahi *et al*. (2014), two species of hyper parasitoids were collected from mummified aphids which were *Pachyneuron aphidis* (Bouché) (Hymeniptera: Pteromalidae) and *Pachyneuron groenlandicum* (Holmgren) (Hymenoptera: Pteromalidae). Cobblah *et al*. (2012) also recorded four facultative parasitoids on DBM (*Oomyzus sokolowskii*, *Aphanogmus reticulatus*, *Elasmus* sp. and *Trichomalopsis* sp.) and two primary parasitoids (*Pediobius* sp. and *Hockeria* sp.)

2.7.6.5 Black ants (Hymenoptera: Formicidae)

The black carpenter ants have been recorded as important natural enemies in cabbage fields (Fening *et al*., 2013). Predation of two species of *Iridomyrmex* ants has been reported in the Canberra area (Australia) to have reduced the numbers of *Pieris rapae* juvenile stages (Jones, 1987). They possess powerful mandibles that are used to attack other insects, so they may act as predators of pests. However, they also protect aphid colonies by tendering them, and thus may as well be regarded as pests in cabbage fields (Fening *et al*., 2013). Black ants in turn benefit from the honeydew produced by the aphid.

2.8 Resistance development

Resistance is a genetically-based characteristic in which an organism remains unaffected by a pesticide dose that previously killed it (Francis *et al*., 2005). Due to genetic mutation and inheritance, resistance genes occur naturally in individual pest populations and as a result of the process of selection, they spread throughout the population resulting from repeated pesticide use. Following pesticide treatment, resistant individuals survive and subsequently reproduce, and the trait for resistance is “selected” in the next generation, while the susceptible individuals are eliminated. If the treatment continues, the percentage of selected survivors will increase and the susceptibility of the population will decline to a point that the pesticide no longer provides an acceptable level of control. Two types of resistances in insects exist, i.e. cross and multiple resistance. In the cross resistance the insect is not affected by chemicals produced from the same group such as pyrethroids, organochlorines, and in multiple resistance the insect is not affected by more than one class of insecticides. For instance, DBM has been reported to have acquired cross resistance to commonly used pyrethroids and multiple resistance to pyrethroids and organophosphates (Odhiambo *et al*., 2010). In Asia and Africa, DBM infestation is especially acute for poor farmers who do not have access to certified insecticides and hence, rely heavily on over usage of toxic and broad spectrum insecticides (Rauf *et al*., 2004) to help reduce pest numbers. DBM has grown resistant to commonly used pesticides and even novel insecticides like spinosad and indoxacarb (Zhao *et al*., 2006) and some strains of the bacterial insecticide, *Bacillus thuringiensis* (Bt) (Shelton *et al*., 2007). In East Africa, reported cases of resistance were found to be as a result of intensive weekly insecticide application by farmers (Cooper, 2002). One major problem which seems to increase this problem is inability of farmers to respect and adhere to recommended spraying volumes and IPM practices (Obeng-Ofori *et al*., 2002; Osei *et al*., 2013). Hence it will be more effective at achieving better results if the above measures are done by incorporating other control options through integrated pest management strategies. A study in Pakistan reported resistance of cabbage aphids to methomyl, emamectin benzoate, pyrethroids and neonicotinoids due to intensive use on vegetables (Ahmad and Akhtar, 2013).

2.9 Effects of shallots against cabbage insect abundance

Planting insect pest repellent plants as companion plants along with crops has been used as an alternative method in pest management (Anonymous, 2004). Alliums are a family of plants which include garlic (*Allium sativum*), chive (*Allium schoenoprasum*), onion (*Allium cepa*), shallot (*Allium ascalonicum* L.), and others. This plant family is particularly beneficial as pest repellent and can repel pests such as: cabbage maggots, cabbage worms, cabbage loopers, Japanese beetles and aphids (Mateeva *et al*., 2002; Kirtikar and Basu, 1975). This repellence is attributed to sulfur containing compounds found in these plants (Block *et al*., 1992; Kim *et al*., 2004). They equally possess very effective antifeedant properties (Simmonds *et al*., 1992) and this approach is environmentally friendly and enhances natural enemy presence (Luchen, 2001; Katsaruware and Dubiwa, 2014).

Shallots or multiplier onions were introduced in Ghana in 1800 from Anecho in neighbouring republic of Togo and cultivated in the country for more than a century (Adomako, 1959), especially in the Volta region due to good bulbs from their porous sandy soils and have been simultaneously planted with cabbage in many instances. Shallots contains more flavonoids and phenols than other members of the onion genus and has hypocholesterolemic (Tappayuthpijarn *et al*., 1989), hypoglycemic (Jalal *et al*., 2007) and antioxidant (Leelarungrayub *et al*., 2006), antifungal and anti-bacteria effects (Amin and Kapadnis, 2005). More so, shallots have repellent effects against certain pests of cabbage

(Mateeva *et al*., 2002) and therefore as a border crop, a physical barrier to the movement of insect pests is created hence the targets (cabbage) cannot be reached. This barrier disrupts the visual and olfactory cues between the insects and the cabbage (Asare- Bediako *et al*., 2010 and Said and Itulya, 2003). This makes the insect pests ineffective in their feeding and egg laying, the natural enemies then increase in number to effectively manage the insect pests. Sinnadurai and Abu (1977) reported that the scent of shallots and onions repels snakes and are planted near homes and gardens for that purpose. Sullivan (2003) noted that, if susceptible plants are separated by non- host plants such as shallots that can act as a physical barrier to the pest, the susceptible plant will suffer less damage. More so, the effectiveness of these non-host plants is dependent on sufficient repellent properties which accumulates as leaves develops, implying that the timing of planting is crucial as indicated by Shankar *et al*., 2005 and Lü and Liu, 2008. For example, trials conducted in India showed that planting a row of tomato 30 days before cauliflower significantly reduced the incidence of *P. xylostella* (Kandoria *et al*., 1999) whilst Hasheela *et al*. (2010) in a similar study showed reduced *P. xylostella* numbers on cabbage borded with Indian mustard which was planted 15days prior cabbage. Therefore, the study of repellent behaviour and sowing time of some plant species to different insect pests reveals new opportunities for decrease of chemical use, especially in vegetable-growing.

2.10 Effect of shallot on cabbage production and yield

Cabbage yield range between 80-120 tons per hectare depending on season of production and level of management. The importance of growing cabbage is mainly for the heads. Marketable heads are determined by the level of damage (Baidoo *et al*., 2012). Less damage to head implies a relatively higher price and more damage to heads implies a lower price, to the extent that it can even be rendered unmarketable (zero price). The use of shallots as border crop is therefore to reduce insect pest numbers and hence reduce damage levels and consequently increase yield. Work conducted by Katsaruware and Dubiwa (2014) in Zimbabwe showed that cabbage onion intercrop gave a higher mean total marketable heads weight of 22.4 kg while the control (sole cabbage) produced a mean total heads weight of 17.8 kg, with the increase in head weight attributed to lower pest attack. This is economically important to compensate for the lesser number of heads because of the space used for the intercrop (Cerruti *et al*., 2002)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The research was carried out at Adzablikope, Lowcost and Mifetukope which are cabbage production areas in the Ketu-South municipality of the Volta region (Plate 9). Due to land scarcity, these were the only available pieces of lands donated by referenced farmers for this project. Ketu South is one of the 25 districts in the Volta Region of Ghana and lies between Latitudes 6°00'N and 6°10'N and Longitudes 1°00'E and 1°10'E. The district is bonded by the Gulf of Guinea to the South, Togo to the East, Keta Municipal District to the West and Ketu North District to the North (http://ketusouth.ghanadistricts.gov.gh). It has three main geological formations namely the Dahomenyan formation to the North made up of soils such as Tropical Grey and Black Earths, the Regosolic Groundwater Laterites, the Recent Deposits of the littoral consisting of marine sands and the Tertiary formation comprising Savannah Ochrosols for its soil type. These soil types are suitable for the cultivation of different types of crops. It has an equatorial climate with average monthly temperatures between 24℃ and 30℃ and mean annual rainfall of 850mm to 1,000mm. The rainfall is of double maxima type occurring from April to July and September to October. The dry season, which is dominated by the dry harmattan winds, extends from December to February.

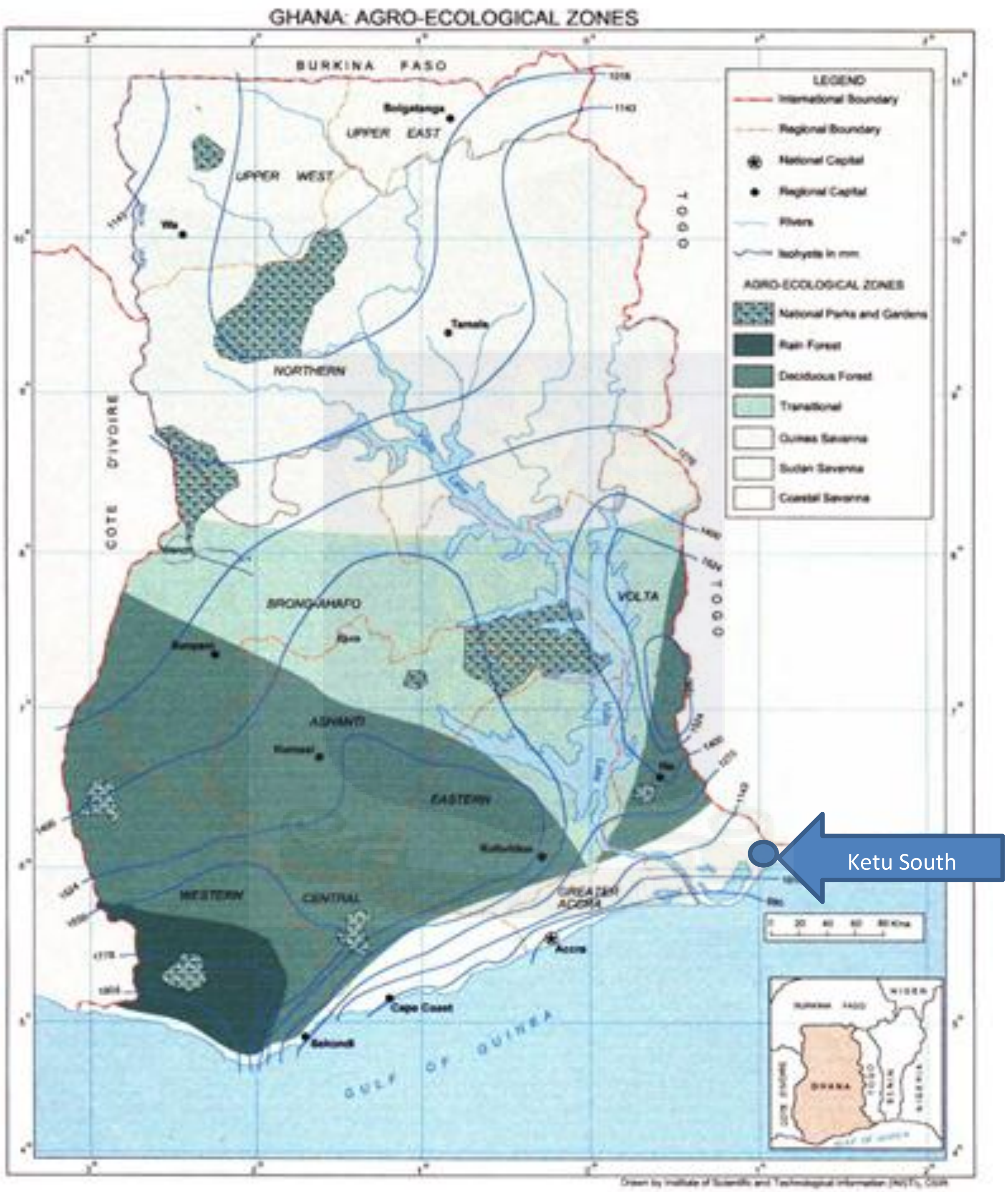


Plate 9: Map of Ghana showing the study site (source: Forchibe, 2016).

3.2 Experimental design

The experiment was a split-plot laid out in a Randomized Complete Block Design (RCBD) with cabbage varieties as the main plots and six pest management strategies as sub plots. Each treatment had three replicates or blocks, with each replicate on a similar, but separate community (farmer's farm), in order to promote the adoption and dissemination of IPM strategies among farmers in this area. Each block consisted of 12 plots, giving a total of 36 plots. Each plot size was 5m long and 2m wide (10m^2) and an alley of 1m and 1.5 m was maintained between individual plots and varieties, respectively. The experiment was carried out during the wet (major: July- October, 2016) and dry (minor: November 2016- February 2017) growing seasons to coincide with farmers planting time. Field layout and randomization was as shown in plate 10.

Replicate 1(Adzablikope)

T_1	T_2	T_3	T_4	T_5	T_6	Oxylus
T_2	T_3	T_4	T_6	T_1	T_5	KK cross

Replicate 2 (Lowcost)

T_6	T_3	T_5	T_1	T_4	T_2	Oxylus
T_5	T_4	T_6	T_2	T_3	T_1	KK cross

Replicate 3 (Mifetukope)

T_4	T_2	T_3	T_6	T_5	T_1	Oxylus
T_1	T_5	T_2	T_3	T_6	T_4	KK cross

Plate 10: Field layout and randomization

3.3 Treatment details

There were a total of 12 treatment combinations consisting of cabbage varieties and the management strategies (2 cabbage varieties x 5 management strategies + 2 controls = 12) (Table 7) with three replications. The main treatment plots were cabbage varieties; KK cross and Oxylus which are preferred by farmers in this locality. The sub plots were the management strategies which consisted of Neem seed water extract, Bypel 1® (PrGV + Bt) insectiicide, shallots planted 14 days prior to cabbage transplanting, shallot planted 7 days prior to cabbage transplanting, shallot planted with cabbage on the same day combined with a short duration of Neem spray and control (Table 6).

Table 6: Detailed description of the pest management strategies and cabbage varieties.

Acronym	Management strategy
T_1	Shallot planted the same time with cabbage combined with short duration of Neem spray
T_2	Aqueous neem seed extract
T_3	Shallot planted 7 days before transplanting cabbage
T_4	Shallot planted 14 days before transplanting cabbage
T_5	Bypel 1® (PrGV+Bt) commercial insecticide
T_6	Control
	Cabbage variety
V_1	Oxylus
V_2	KK cross

Table 7: Treatment combinations, description and application rates.

Treatment (combination) acronym	Description and application rate/time
V_1T_1	Oxylus planted at the same time with shallot, combined with a short duration neem spray, 50g/l (75kg/ha)
V_1T_2	Oxylus and aqueous neem seed extract, 50g/l (75kg/ha)
V_1T_3	Shallot planted 7 days before oxylus
V_1T_4	Shallot planted 14 days before oxylus
V_1T_5	Oxylus and Bypel 1® (PrGV +Bt) insecticide, 2kg/ha
V_1T_6	Control (sole oxylus)
V_2T_1	KK cross planted with shallot at the same time, combined with a short duration neem spray, 50g/l (75kg/ha)
V_2T_2	KK cross and aqueous neem seed extract, 50g/l (75kg/ha)
V_2T_3	Shallot planted 7 days before KK cross
V_2T_4	Shallot planted 14 days before KK cross
V_2T_5	Oxylus and Bypel 1® ((PrGV +Bt) insecticide, 2kg/ha
V_2T_6	Control (sole KK cross)

3.4 Land preparation and nursery establishment

3.4.1 Land preparation

Land for experimental plots were cleared of weeds and tilled to loosen the sandy soil and to avoid compaction. Beds were made with hoes as done by the local farmers to allow for proper irrigation of the fields and good flow of water through the furrows. A fifty-meter measuring tape was used to demarcate the plots according to the specified dimensions (2m x 5m).

3.4.2 Selection of seeds

Disease free certified healthy hybrid white cabbage (*B. oleracea* var. *capitata*) (cv. Oxylus) and (*B. oleracea* var. *capitata*) (cv. KK cross) seeds were purchased from Aglow Company limited, an agro based certified input shop in Accra, Ghana. The seeds were packaged with transparent non porus polybags and stored in a well-ventilated room till the nursery was established to ensure good seed viability.

3.4.3 Nursery establishment

Nursery beds at 5m x 1m were tilled with a hoe, and well decomposed poultry manure (10t/ha) was mixed with the soil and allowed for a week before sowing of seeds. This was done to prevent heat generated by any microbes left in the manure from destroying the seeds. Line sowing of KK cross and oxylus seeds, 10cm apart on separate nursery beds was done on the 11th of July 2016 and 9th November 2016 for the major and minor rainy seasons, respectively. The beds were covered with pest- free dried palm fronds as practiced by the local farmers, which were later removed four days after sowing of seeds to avoid distortion of seedling growth.

Cultural practices such as hand picking of weeds and thinning out were carried out every three days and watering was done daily, in the mornings and evenings to increase plant vigour and ensure healthy growth of the seedlings. A week before transplanting, the seedlings were irrigated once every two days, to reduce transplanting shock and to acclimatize them to field conditions. Plate 11 shows nursery beds for both cabbage varieties.

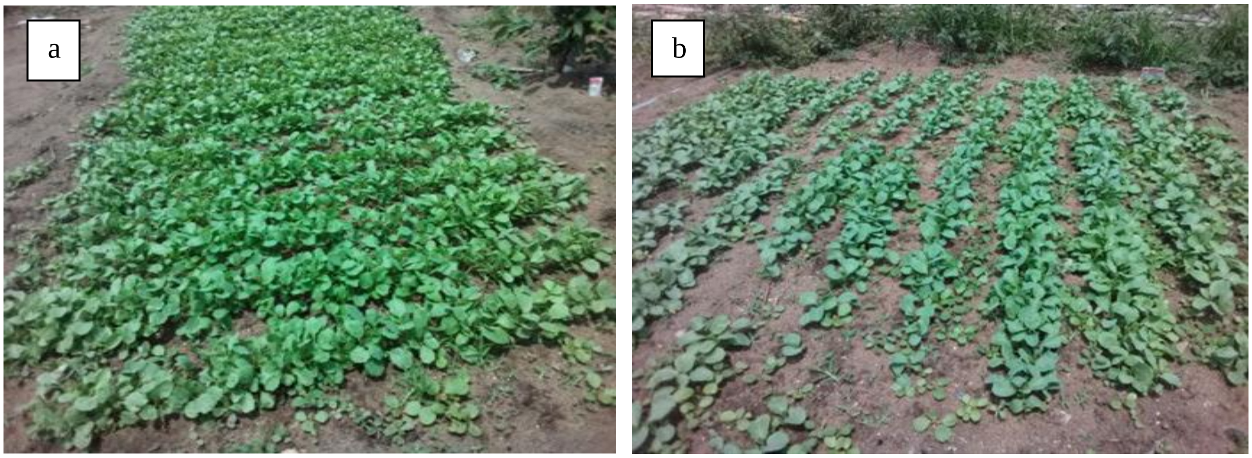


Plate 11: Cabbage nurseries; (a) cabbage variety oxylus and (b) cabbage variety KK cross

3.5 Planting of shallots

Shallot (*Allium ascalonicum* L.), from the family Alliaceae due to its availability in the Volta region was used a border crop at an intra-spacing of 20cm. The shallot bulbs were obtained from Anloga local Market in the Volta region (Plate 12), and planted round the intended plots at different dates: 18th July, 25th July and 2nd August, 2016 for the major season and 24th November, 1st December and 8th December, 2016 for the minor season (which represented 0, 7 and 14 days), before cabbages were transplanted onto the field (Plate 13). This was done to determine the optimal planting date that sufficient properties can be accumulated to repel key pests of cabbage.

Plate 12: Shallot bulbs.

Plate 13: Shallots sown 7 days before cabbage transplanting (a) and cabbage planted 14 days before cabbage transplanting (b)

3.6 Transplanting of cabbage seedlings

Four weeks old healthy cabbage seedlings with about five true leaves were selected for transplanting to ensure good survival and uniform establishment of the crops. They were transplanted on 2nd August and 8th December, first and second cropping season, respectively, onto prepared plots spaced at 50 cm inter-row and 50 cm intra-row. The experimental field was irrigated before transplanting was done to enable sufficient moisture in the soil which promotes good nursery establishment. Sticks were used to create transplanting holes and the seedlings were transplanted 2cm deep into the soil to avoid deterioration of the below ground parts. Each bed had 4 rows of cabbage and each row had 10 plants, giving a total of 40 cabbages per plot. Plots were labeled by randomly assigning treatment to them. Gray boards were used for labeling treatment plots (Plate 14).

Plate 14: Gray labeled boards (a) and Cabbage transplanted in the field on labeled plots (b).

3.7 Fertilizer application

Cow dung, 20t/ha, was incorporated into the soil one week before planting to allow for proper decomposition and avoid the heat produced by microbes from burning the seedlings. There were application into the soil of NPK 15-15-15 (180ml/plant) and Sulphate of Ammonia (3g/plant) 7 and 42 days, respectively, after transplanting during the major and minor seasons to supply the necessary nutrients needed for healthy plant growth.

3.8 Weed control and watering (irrigation)

Weeds compete with field crops for essential components such as, carbon dioxide, sunlight, space and soil nutrients. Weeding was carried out at fourthnightly intervals with a small and narrow edged hoe (6 cm). The field was irrigated thrice a week using sprinklers and irrigation pipes. Sprinklers were positioned at vantage points while irrigation pipes were place on furrows and around the beds on the field (Plate 15) and water was pumped into the field from a nearby pond. However, when there was rainfall, irrigation was done depending on the intensity and duration of the rain.

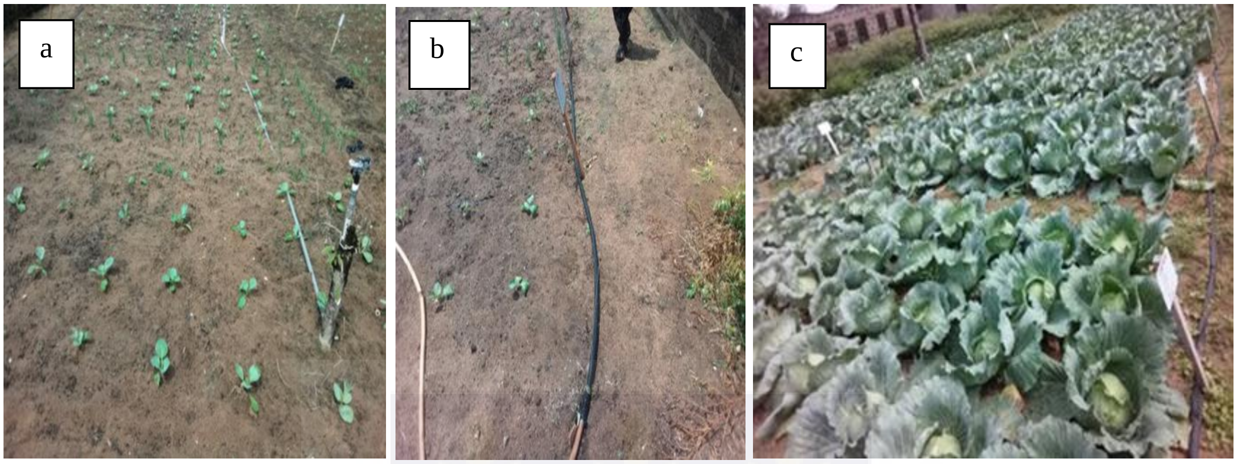


Plate 15: Sprinklers (a) and irrigation pipes (b) laid in the field; full grown cabbages in the field (c).

3.9 Preparation of treatments

The commercial insecticide, Bypel 1® (PrGV+Bt) is marketed in Ghana by Aglow Company, and Abnark Agro Services, Kumasi. It is a fully registered insecticide with registration number 13133/00648G and an issue date of October, 2015. Its active ingredient comprises a mixture of *Peris rapae* Granulosis Virus and *Bacillus thuringiensis* and it has a hazard class of II (Revised Register of Pesticides, December 2015). Bypel 1® is a biological insecticide and is effective against lepidopteran insect pests of vegetables, fruits, cotton, nuts, corn, soyabean and other crops (Plate 16). The spray liquid was prepared by mixing 1.5g/1litre of water in a 15litre Jacto knapsack sprayer following the manufacturer's recommendation.

Plate 16: Bypel 1® insecticide.

3.9.1 Neem seed collection, drying and extract preparation

Fully matured neem seeds and dropped neem fruits were collected from neem trees and sorted out to remove mouldy ones. The fruits were depulped and dried in the shade for 14days at room temperature (28 + 2 °C). Dried seeds were later stored in baskets in a dry and well- ventilated room to prevent the formation of mould. When needed, 50g of neem seeds were crushed in a mortar using a pistle. The crushed seeds were dissolved in one litre of water and stirred. Two drops of liquid soap and oil were added to the mixture and allowed to stand overnight (Plate 17). The mixture was then filtered using a fine cloth and the clear extract containing the active ingredient (azadiractin) was poured into a 15L knapsack and sprayed onto the cabbage plants while the residue was discarded.

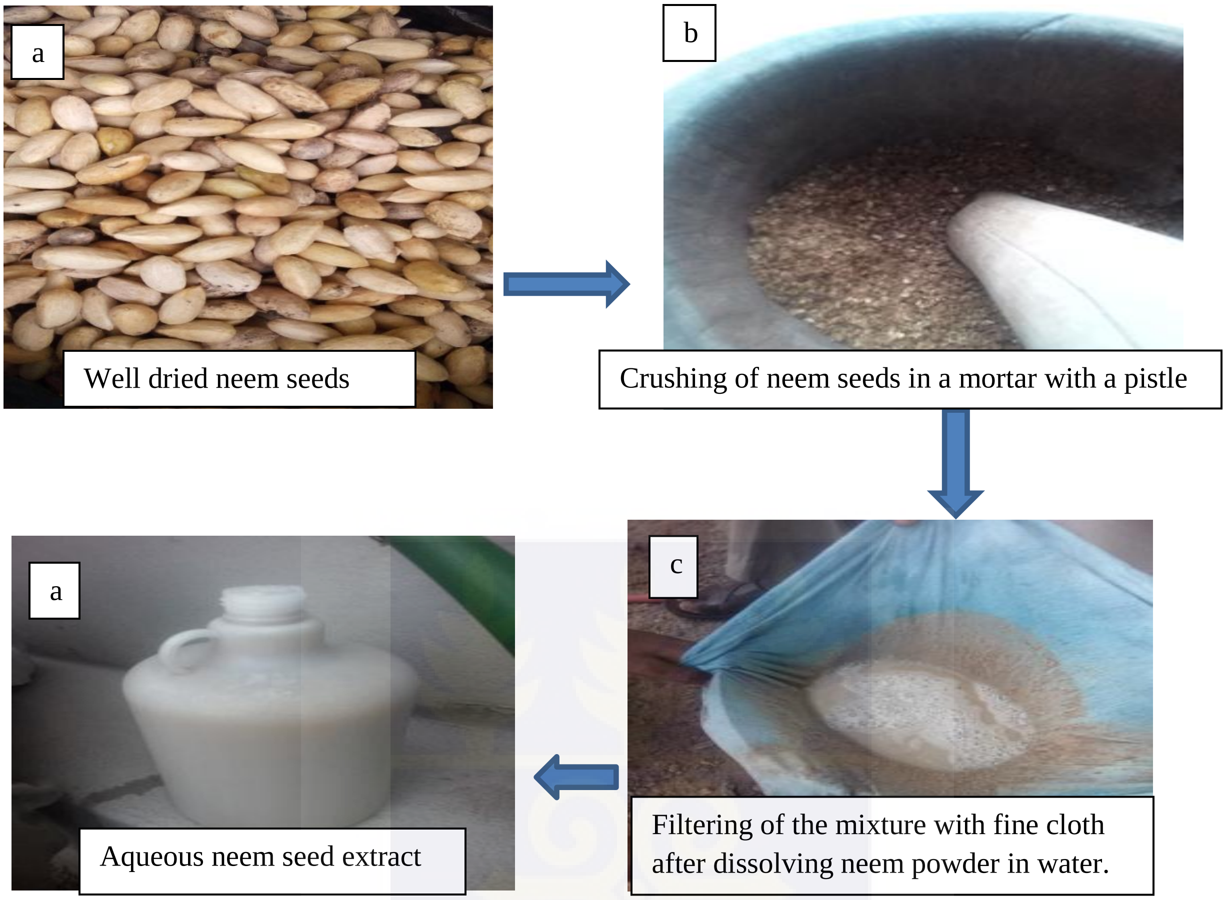


Plate 17: Neem seeds and the different steps involved in the extract preparation.

3.10 Application of treatments

Insecticide treatments were applied after scouting, 21 days after transplanting of cabbage seedlings when insect pests were detected during the major season and 14 days after transplanting in the minor season due to the early occurrence of insect pests on the field. Neem seed extract (50g/L of water) and Bypel 1® (1.5g/L of water) treatments were sprayed using a 15l Jacto knapsack sprayer with a cone nozzle. Spraying was carried out in the evening to prevent photo-breakdown of chemicals and maximum coverage of leaves including underneath leaf surfaces where pests normally hide. This was repeated weekly until the cabbage heads were fully matured, 14 days to harvesting.

3.11 Yellow sticky traps

Yellow Ceiling board measuring 30 cm x 25cm were inserted into a transparent polybag and an adhesive (grease, ABRO #3 super heavy-duty grease) (Banfo, 2009) was applied on both sites to catch flying insects (Plate 18). The sticky boards were fastened to pieces of wood with nails and randomly pinned separately at the center of each plot for both varieties. The trap's height was adjusted as the plants grew to fit the heights of cabbage plants. To minimize effects due to the position of the traps on the insect catch, they were re-randomize every two weeks.

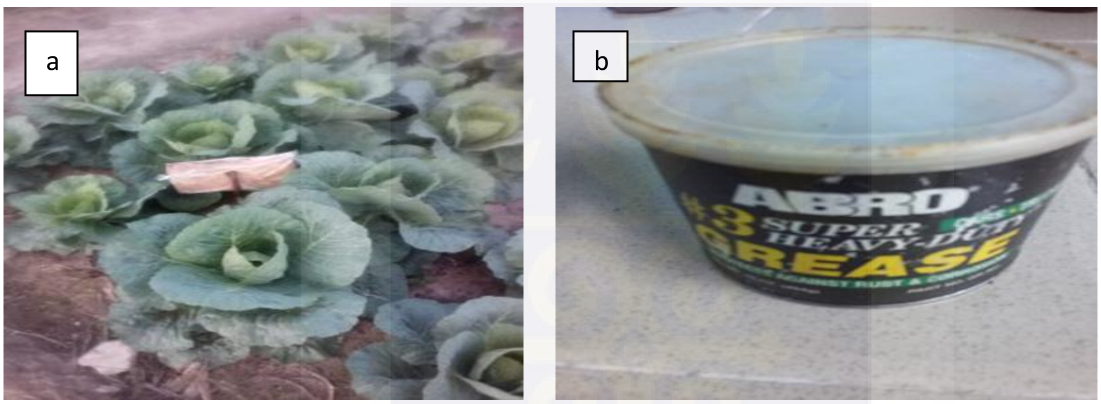


Plate 18: (a) Sticky trap and (b) grease used for trapping insects.

3.12 Data collection

Data was taken from 6:00 am to 8:30 am weekly and up to two weeks before harvesting during the major and minor cropping seasons. Data collection was done three days after application of treatments. Data collected included: DBM number per 10 plants per plot, cabbage webworm number per 10 plants per plot, aphid score per 10 plants per plot, abundance of other insect pest of cabbage as well as natural enemies, multiple heads formation, marketable heads, cabbage yield, damage score, counts of plants without heads and the number of rotten cabbage heads. Plants in the inner rows were selected at random and used for data collection. Cabbages from the inner rows were used for assessing pest counts, damage and yield to prevent bias since conditions in the inner rows remained stable and uniform for all plots than the outer border rows where the variation is quiet high.

3.13 Sampling of insects

Insects were sampled using sticky traps and by hand picking. The 30cm x 30cm polybags were removed from the sticky traps and replaced with new ones every week. The insects were picked individually from the polybags with a pair of forceps using a hand lens. The insects were preserved in well labeled plastic containers containing 70% ethyl alcohol. Additionally, insects were handpicked and preserved for identification. The arthropods collected were sent to the Entomology Laboratory of African Regional Postgraduate Programme in Insect Science, University of Ghana, Legon, for identification using morphological features and reference specimens.

3.13.1 Sampling for *Plutella xylostella*

P. xylostella larvae were counted in situ by opening up the young fold of cabbage leaves where eggs are laid and hatch into caterpillars as well as searching all other parts of the opened leaves especially from beneath. The densities of DBM were determined by recording the number of larvae observed (Phillips, 1983). Observed pupae and adults were counted and recorded.

3.13.2 Sampling for *Hellula undalis*

Ten plants were randomly selected within the middle rows of each experimental unit and in situ counts of *H. undalis* larvae and pupae were made and recorded.

3.13.3 Sampling for aphids

The cabbage leaves were examined from the base to the upper leaves and insects were counted. The aphids due to their large numbers are difficult to count hence were scored from 0-5 as described by Afun *et al*. (1991) and Fening *et al*. (2014a) 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. Other insect pests found in the field were sampled by weekly field observations, counting and recording of their populations. This was done by inspecting ten plants per treatment plot for their presence.

3.13.4 Sampling of natural enemies

Ten plants in the inner rows were carefully examined by searching the leaf surfaces and by gently searching the underside of cabbage leaves to count and record the populations of different natural enemies observed.

3.14 Assessment of yield and damage

3.14.1 Harvesting of cabbage heads for yield

KK cross matured earlier and was harvested at two months, three weeks while oxylus was harvested at 3 months, two weeks after last treatment application. Fifteen cabbage plants from the inner rows were harvested by cutting the cabbage heads for each plot. The cabbage heads were weighed using a Salter balance (Plate 19) and the weights (kg) were recorded. The yield per unit area was extrapolated into tonnes per hectare (ton/ha) and this is given by;

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

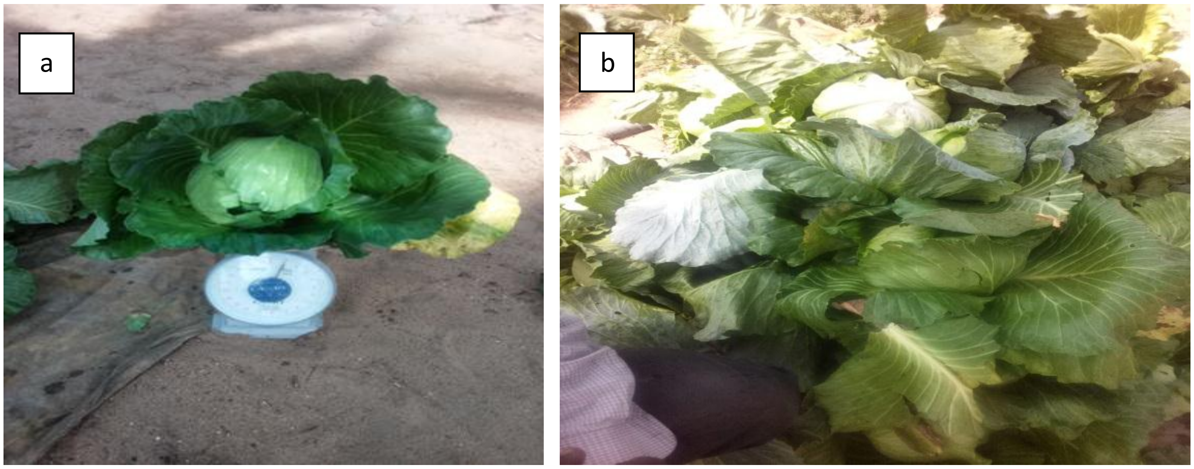


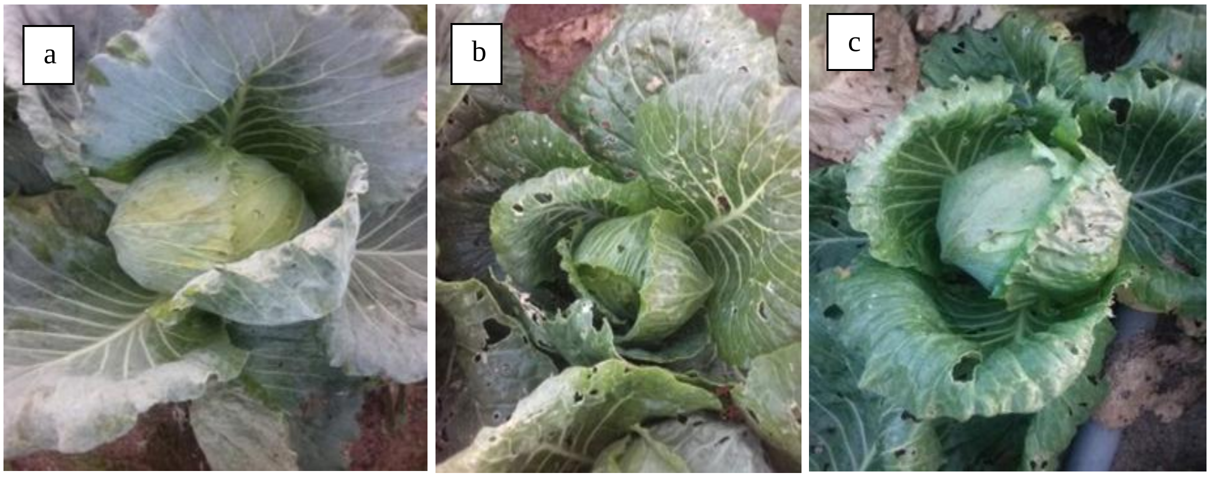
Plate 19: Scale for weighing cabbages (a) and cabbage heads (b) after harvesting.

3.13.2 Yield quality/ crop health

Crop health was evaluated based on the damage on the harvested heads. Cabbage head damage was assessed by using a standard scoring scale of 0-5 (Aboagye, 1996). 0= no head damage 1= 1-15% head damage, 2= 15-30% head damage, 3=30- 45% head damage, 4= 45-60% head damage and 5= 60- 100% head damage, which represent the unmarketable class. The harvested heads were marked as marketable and unmarketable (Plate 20) and their percentages calculated for each treatment (Munthali and Tshegofatso, 2014).

$$\% \text{ damage} = \frac{\text{Total number of damaged heads}}{\text{Total number of heads sampled}} \times 100$$

$$\% \text{ of marketable heads} = \frac{\text{Total number of marketable heads}}{\text{Total number of heads sampled}} \times 100$$



0= no damage 1=1-15%damage 2=15-30% damage

3= 30-45% damage 4=45-60% damage 5= above 60% damage

(Unmarketable)

(Photo taken by Nkafu Therese Ngosong).

Plate 20: Cabbage heads damaged by pests and their respective damage scores; (a) cabbage head showing no damage, (b) cabbage head showing 1-15%damage, (c) cabbage head showing 15-30% damage, (d) cabbage head showing 30-45% damage, (e) cabbage head showing 45-60% damage, (f) cabbage head with above 60% damage (Unmarketable).

3.13.3 Multiple head assessment

The number of multiple heads were counted per plot and recorded. The percentage multiple heads formed was calculated by dividing the number of plants with multiple heads by the total number of plants and multiplied by 100% as;

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

Also, the number of rotten heads were counted per treatment plot and recorded. The percentage rotten heads formed was calculated by dividing the number of plants with rotten heads by the total number of plants and multiplied by 100% as;

$$\%\text{ of rotten heads} = \frac{\text{Total number of rotten heads}}{\text{Total number of heads}} \times 100$$

3.14 Data Analysis

Data on insect pests and natural enemies were analysed using repeated measures of analysis of variance (ANOVA) and other data on insect damage and the yield of cabbage were analysed using ANOVA. Where significant differences existed, mean separation was done using LSD at 5% significant level. Count data was square root transformed, whereas data on percentages was arcsine square root transformed before analysis. Student t test was used to compare data between the two seasons. Back transformation was however reported in Tables and text.

CHAPTER FOUR

4.0 RESULTS

4.1 Insect fauna found on cabbage field during the major and minor seasons.

The cabbage plants attracted a number of insect pests at different stages of the plant growth due to their luxuriant and nutritive nature. The pest complex included the diamondback moth (*Plutella xylostella*), the cabbage aphids (*Brevicoryne brassicae)* and cabbage webworm (*Hellula undalis*). Other insect pests encountered apart from the key pests were: *Bemisia tabaci* (whiteflies), thrips (*Thrips tabaci*), grasshoppers (*Zonocerus variegatus*), cabbage looper (*Trichoplusia ni*) and plant hoppers (*Empoasca* spp.). The cutworm (*Spodoptera littoralis*) was only spotted in the minor season. Snails were equally present in both seasons (Table 8).

Table 8: Mean percentage abundance of different pests during the major and minor seasons.

	Mean % abundance	
Insect pests	**major season**	**Minor season**
P. xylostella	1.33	0.82
H. undalis	0.44	0.27
B. brassicae	1.70	0.88
B. tabaci	3.74	50.17
T. tabaci	80.81	36.02
Z. variegatus	0.52	0.76
Emposca spp	0.13	-
T. ni	-	0.26
Snails	11.34	12.50

4.2 Effects of different management strategies on the population of key pests of two cabbage varieties during the major and minor season.

4.2.1 *Plutella xylostella*

Plutella xylostella numbers (0.1 – 0.7/plant and 0.2 – 1.4/plant, for both seasons) started building up from the first week of sampling and the population was at its peak in the sixth and fifth week for the major and minor seasons, respectively. *Plutella xylostella* was absent in some weeks in Bypel 1® treatment, neem treatment and on shallot plot with a short duration neem spray (Figures 2 and 3). The effect of the pest management strategies on the abundance of DBM for the major and minor seasons were significant ($F_{5, 22} = 6.17$, $P = 0.0010$ and $F_{5, 22} = 45.98$, $P = < 0.0010$). Bypel 1® treatment had the lowest level of infestation but did not significantly differ from the other pest management strategies except for the control in the major season (Table 9a). In the minor season, the various pest management treatments significantly differed from the control; plots treated with aqueous neem seed extract and Bypel 1® had the least number of *P. xylostella* and differed significantly from shallot treatments planted 7 and 14 days prior cabbage (Table 9b). The cabbage variety, KK cross, had more numbers of *P. xylostella* than oxylus (appendix 1), but both varieties did not significantly differ from each other in both seasons ($F_{1, 22} = 0.84$, $P = 0.3690$ and $F_{1, 22} = 2.50$, $P = 0.1280$). The interaction between the various management strategies and varieties did not significantly contribute to the number of DBM larvae present on the crop for both seasons ($F_{5, 22} = 0.18$, $P = 0.9690$ and $F_{5, 22} = 0.44$, $P = 0.8180$). The weeks of sampling had a significant effect on the numbers of *P. xylostella* for both seasons ($F_{5, 120} = 4.89$, $P = 0.0010$ and $F_{6, 144} = 6.49$, $P < 0.0010$, respectively). There was also a significant difference on the effects of the different management strategies on the population of *P. xylostella* among the weeks of sampling for both seasons ($F_{25, 120} = 1.80$, $P = 0.0340$ and $F_{30, 144} = 1.97$, $P = 0.0180$). However, the interaction between the weeks and the varieties was not significant for both seasons ($F_{5, 120} = 0.69$, $P = 0.5930$ and $F_{6, 144} = 0.76$, $P = 0.5440$). The interaction between the varieties and management strategies among the weeks of sampling was also not significant for both seasons ($F_{25, 215} = 0.79$, $P = 0.7100$ and $F_{30, 144} = 0.60$, $P = 0.9000$). A *t* test revealed that the number of

DBM larvae were significantly higher in the minor than the major season ($t_{0.05, 39} = 3.05$, $P = 0.0040$) (appendix 3).

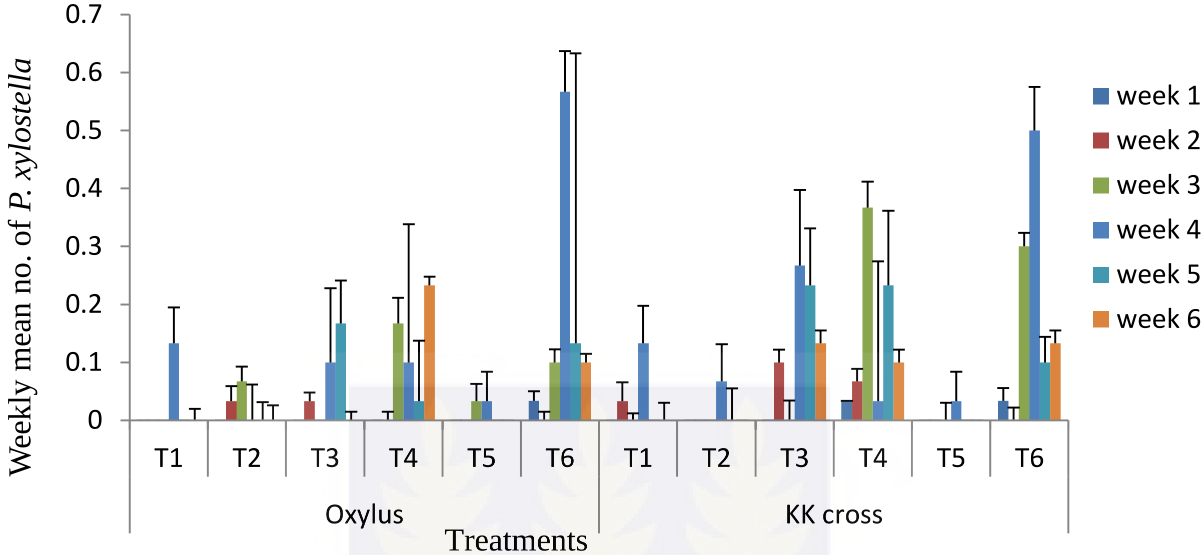


Figure 2: Effects of pest management strategies on mean (±SE) weekly counts of *P. xylostella* larvae per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

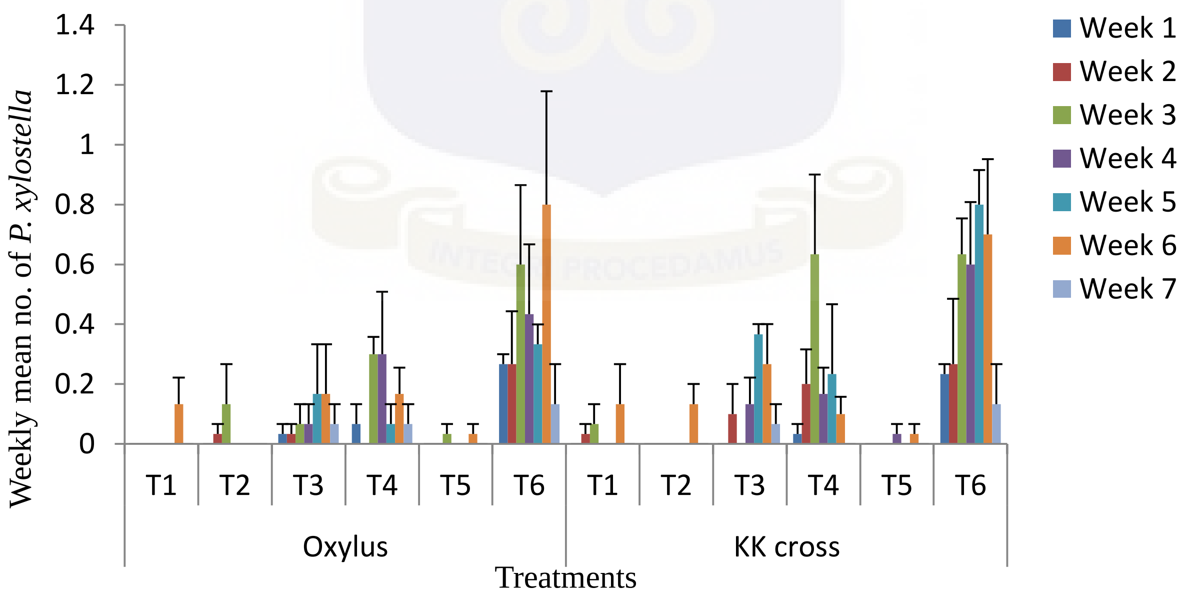


Figure 3: Effects of pest management strategies on mean (±SE) weekly counts of *P. xylostella* larvae per cabbage variety during the major season, 2017, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4. 2.2 *Brevicoryne brassicae*

The population of *B. brassicae* started building up from the second week of sampling and peaks were recorded between fourth and fifth weeks, with a decrease thereafter (Figures 4 and 5). Shallot planted with cabbage on the same day with a short duration of neem spray did not record any aphids whilst the control recorded the highest population of aphids for both seasons. The effect of the management strategies on the abundance of *B. brassicae* was significant for both seasons ($F_{5, 2 2}$= 3.35, P = 0.0210 and $F_{5, 2 2}$= 6.87, P < 0.0010). Shallot planted 14 and 7 days before cabbage and control plots did not differ from each other but differed significantly from Bypel 1® and neem treatments in the major season as opposed to the minor season, where, the various management strategies differed significantly from the control, but not among each other, although shallot/cabbage planted the same day with a short neem spray recorded the lowest population. KK cross had higher aphids population than oxylus but there was no significant difference between the two varieties in both seasons ($F_{1, 22}$ = 0.311, P = 0.5830 and $F_{1, 22}$ = 0.91, P = 0.3500). The interaction between the varieties and various treatments did not significantly affect the *B. brassicae* score for both seasons ($F_{5, 22}$ = 0.22, P = 0.9480 and $F_{5, 22}$ = 0.34, P = 0.8840). The weeks of sampling had a significant effect on the numbers of *B. brassicae* for both seasons ($F_{5, 120}$ = 4.24, P = 0.0080 and $F_{6, 144}$ = 3.50, P = 0.0240). The interaction between the weeks of sampling and the management strategies did not significantly contribute to *B. brassicae* population for the two seasons ($F_{25, 120}$ = 1.14, P = 0.3360 and $F_{30, 144}$ = 1.59, P = 0.1080). The interaction between the weeks and the varieties was not significant for both seasons ($F_{5, 120}$ = 0.701, P = 0.5580 and $F_{6, 144}$ = 0.42, P = 0.7170). The interaction between the weeks of sampling, the varieties and management strategies was also not significant for both seasons ($F_{25, 120}$ = 0.66, P = 0.8110 and $F_{30, 144}$ = 0.32, P = 0.9890).

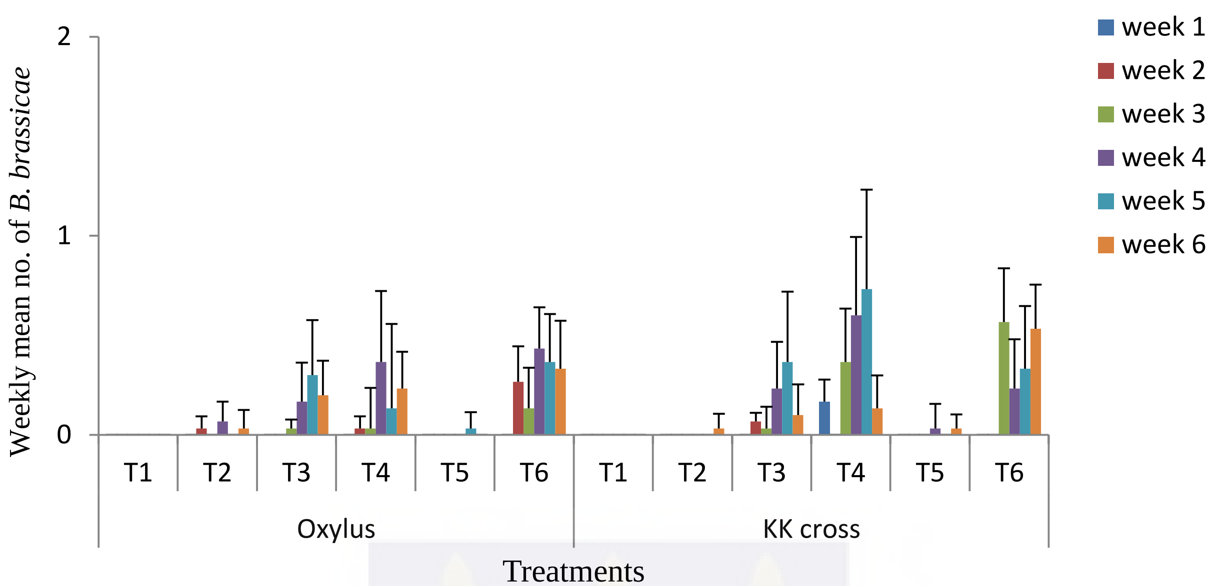


Figure 4: Effects of pest management strategies on mean (±SE) weekly scores of *B. brassicae* per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

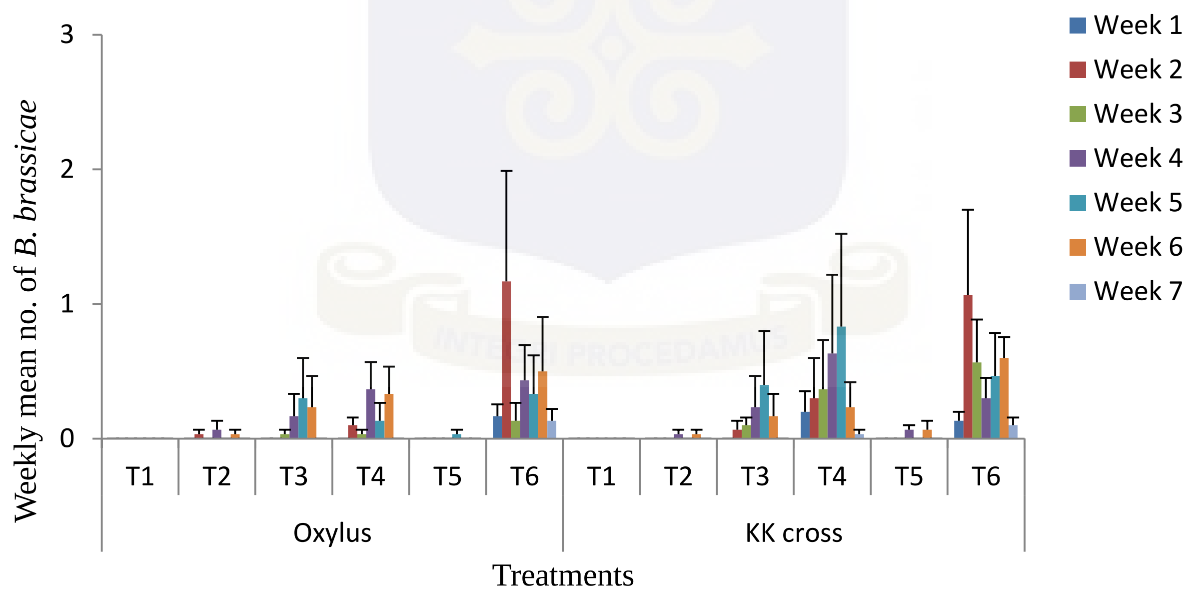


Figure 5: Effects of pest management strategies on mean (±SE) scores of *B. brassicae* per cabbage variety during the minor season, 2017, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.2.3 *Hellula undalis*

The cabbage webworm was first noticed in the first week of sampling and peak populations were recorded on the fourth week depending on the treatments (0.1 – 0.6/plant) in the major season whilst in the minor season, peaks occurred during the first sampling week (0.1 – 0.7/plant) (Figures 6 and 7). There was a significant difference in the effect of different management strategies on *H. undalis* numbers for both seasons ($F_{5, 22} = 4.77$, $P = 0.0040$ and $F_{5, 22} = 9.05$, $P < 0.0010$). Plots treated with Bypel 1® and aqueous neem seed extract had the lowest infestation level of the cabbage webworm for both seasons, but did not differ significantly from all the other management strategies with the exception of the control plots which recorded highest numbers. Within the shallot treatments, cabbages with shallot planted the same day combined with a short duration neem spray had lower number of *H. undalis* than shallots planted 7 and 14 days prior to cabbage in both seasons. The varietal effect on *H. undalis* numbers was not significant in both seasons ($F_{1, 22} = 0.44$, $P = 0.5120$ and $F_{1, 22} = 0.11$, $P = 0.7470$), with higher populations recorded on oxylus than KK cross (appendix 1 and 2). The interaction between various management strategies and cabbage variety was also not significant for the two seasons ($F_{5, 22} = 0.55$, $P = 0.7380$ and $F_{5, 22} = 0.61$, $P = 0.6960$). The effect of *H. undalis* numbers among the weeks of sampling was not significant for the major season ($F_{5, 120} = 0.82$, $P = 0.4670$) but was significant in the minor season ($F_{6, 144} = 3.19$, $P = 0.0280$), respectively. The interaction between the weeks of sampling and management strategies did not significantly contribute to the numbers of *H. undalis* for the two seasons ($F_{25, 120} = 0.97$, $P = 0.4920$ and $F_{30, 144} = 1.39$, $P = 0.1760$). The weeks of sampling and varieties was not significant for both seasons ($F_{5, 120} = 0.65$, $P = 0.5520$ and $F_{6, 144} = 1.05$, $P = 0.3750$). More so, the interaction between the weeks of sampling, management strategies and the varieties was also not significant for both seasons ($F_{25,}$

$_{120}$ = 0.60, P = 0.8350 and $F_{30, 144}$ = 0.35, P = 0.9870). Comparison between *H. undalis* counts for both seasons revealed higher numbers in the minor season, but differences were not significant ($t_{0.05, 36}$ = 2.04, P = 0.0510) (Appendix 3).

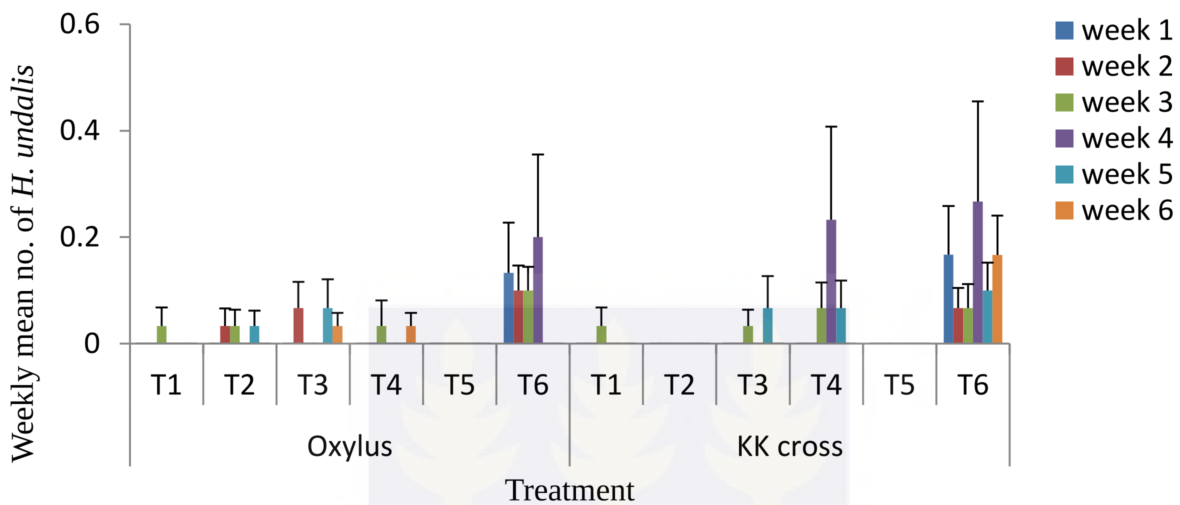


Figure 6: Effects of pest management strategies on mean (±SE) weekly counts of *H. undalis* larvae per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

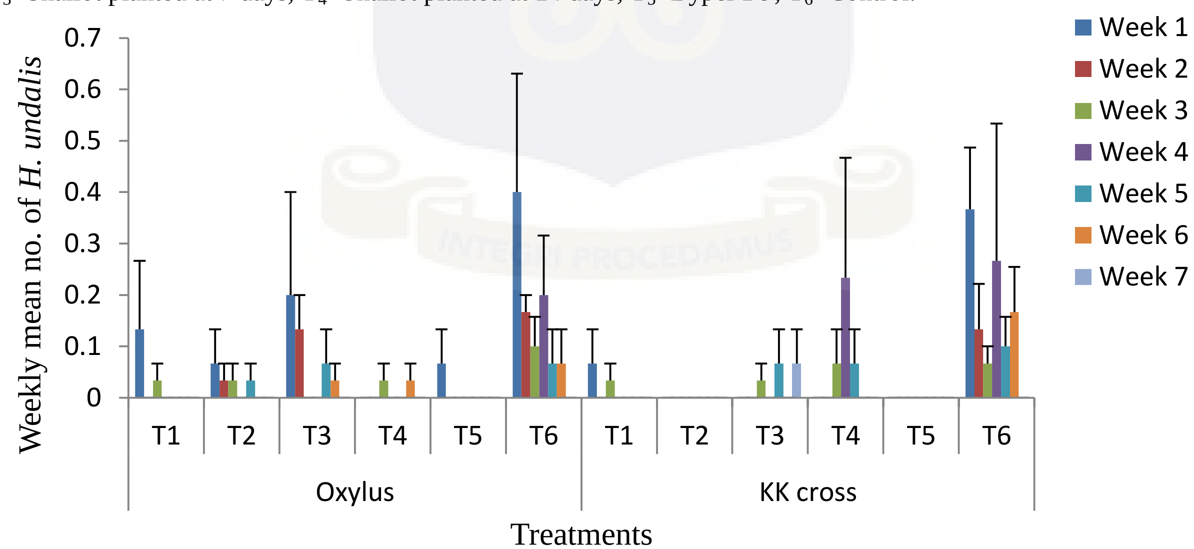


Figure 7: Effects of pest management strategies on mean (±SE) weekly counts of *Hellula undalis* larvae per cabbage variety during the minor season, 2017, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.2.4 Other pests

4.2.4.1 *Bemisia tabaci*

Bemisia tabaci numbers (0.2 – 1.4/plant and 10 – 70/ plant) started rising from the first week of sampling and peaks were recorded on the 2nd and 3rd weeks for the major and minor season, respectively (Figures 8 and 9). The numbers of *B. tabaci* was generally high throughout the sampling period for both seasons. Plots treated with Bypel 1® recorded the least number of *B. tabaci* in the major season, while in the minor season, neem plots recorded the least infestation level. The highest population occurred on control plots for both seasons. There was a significant difference in the effect of different management strategies on *B. tabaci* population for both seasons ($F_{5, 22}$ = 12.61, P = < 0.0010 and $F_{5, 22}$ = 11.77, P < 0.0010). Plots treated with aqueous neem seed extract, Bypel 1® and shallots sprayed with a short duration of neem were not different from each other, but significantly differed from shallots planted 14 and 7 days before cabbage in both seasons. The effect of cabbage varieties on *B. tabaci* numbers was also significant for the two seasons ($F_{1, 22}$ = 7.16, P = 0.0140 and $F_{1, 22}$ = 75.52, P = < 0.0010), where oxylus recorded a significantly higher population than KK cross. The interaction between the various management strategies and the variety was not significant in both seasons ($F_{5, 22}$ = 0.83, P = 0.5450 and $F_{5, 22}$ = 0.52, P = 0.7620). The effect of various management strategies on *B. tabaci* among the weeks of sampling was significant in the two seasons ($F_{5, 120}$ = 24.41, P = < 0.0010 and $F_{6, 144}$ = 21.29, P = < 0.0010). The interaction between the weeks of sampling and management strategies was not significant for both seasons ($F_{25, 120}$ = 0.57, P = 0.8910 and $F_{30, 144}$ = 0.56, P = 0.8860). The weeks of sampling and varieties equally did not have a significant effect for both seasons ($F_{5, 120}$ = 2.27, P = 0.0850 and $F_{6, 144}$ = 1.61, P = 0.1990). The interaction among the weeks, management strategies and varieties were not significant for the two seasons ($F_{25,\ 120}$ = 0.77, P = 0.7130 and $F_{30,\ 144}$ = 0.12, P = 1.0000). However, the minor season had higher population of *B. tabaci* than the major season (appendix 3).

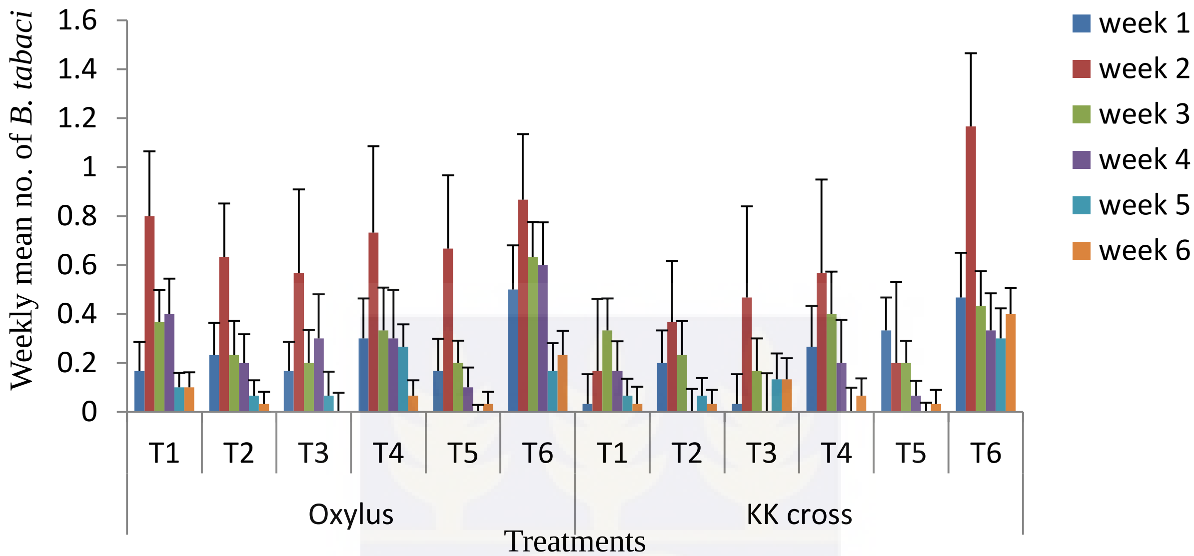


Figure 8: Effects of pest management strategies on mean (±SE) weekly counts of *Bemisia tabaci* per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

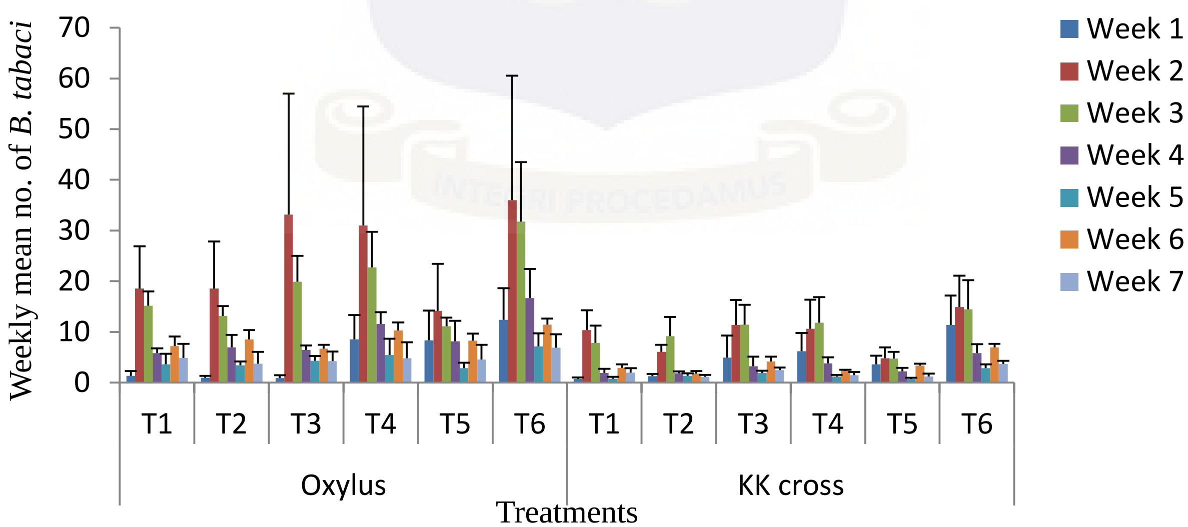


Figure 9: Effects of pest management strategies on mean (±SE) weekly counts of *B. tabaci* per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.2.4.2 Thrips (*T. tabaci*)

The number of thrips started rising up and peaked at the third week of sampling (10 – 70/plant and 10 – 80/plant) for the major and minor seasons (Figures 10 and 11). Infestations on Bypel 1® -treated plots were generally low in the major season whilst neem, Bypel 1® and shallot plots combined with short duration of neem spray had minimal infestation in the minor season, with the highest population on control plots for both seasons. The effect of various management strategies on the number of thrips was significant for the two seasons ($F_{5, 22}$ = 3.33, P = 0.0220 and $F_{5, 22}$ = 3.66, P = 0.0150). The various management strategies differed significantly from the control, but not among each other in both seasons. There was no significant difference in the thrips population for both seasons as per the effect of different varieties ($F_{1, 22}$ = 0.00, P = 0.9660 and $F_{1, 22}$ = 0.07, P = 0.7870), though oxylus had a higher population of this pest than KK cross. There was no significant difference in the number of thrips sampled for both seasons as per the management strategies and the varieties ($F_{5, 22}$ = 0.12, P = 0.9880 and $F_{5, 22}$ = 0.11, P = 0.9880). The effect of weeks of sampling was significant for both seasons ($F_{5, 120}$ = 12.89, P = < 0.0010 and $F_{6, 144}$ = 14.55, P = 0.0150). The interaction between the weeks of sampling and the management strategies was not significant ($F_{25, 120}$ = 0.52, P = 0.8800 and $F_{30, 144}$ = 0.62, P = 0.8210). The effect of the interaction of the weeks of sampling, management strategies and varieties was not significant for both seasons ($F_{25, 120}$ = 0.22, P = 0.9950 and $F_{30, 144}$ = 0.25, P = 0.9950). Comparison between *T. tabaci* counts showed that its population was significantly higher in the minor season ($t_{0.05, 19}$ = 8.41, P = < 0.0010) (appendix 3).

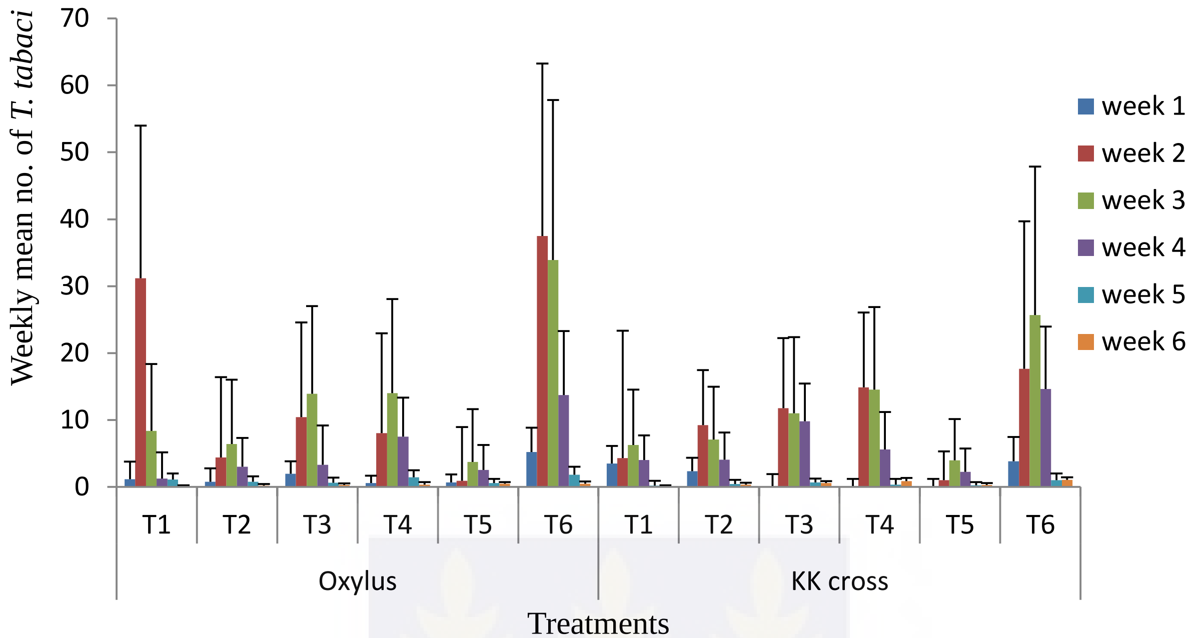


Figure 10: Effects of pest management strategies on mean (±SE) weekly count of *T. tabaci* per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

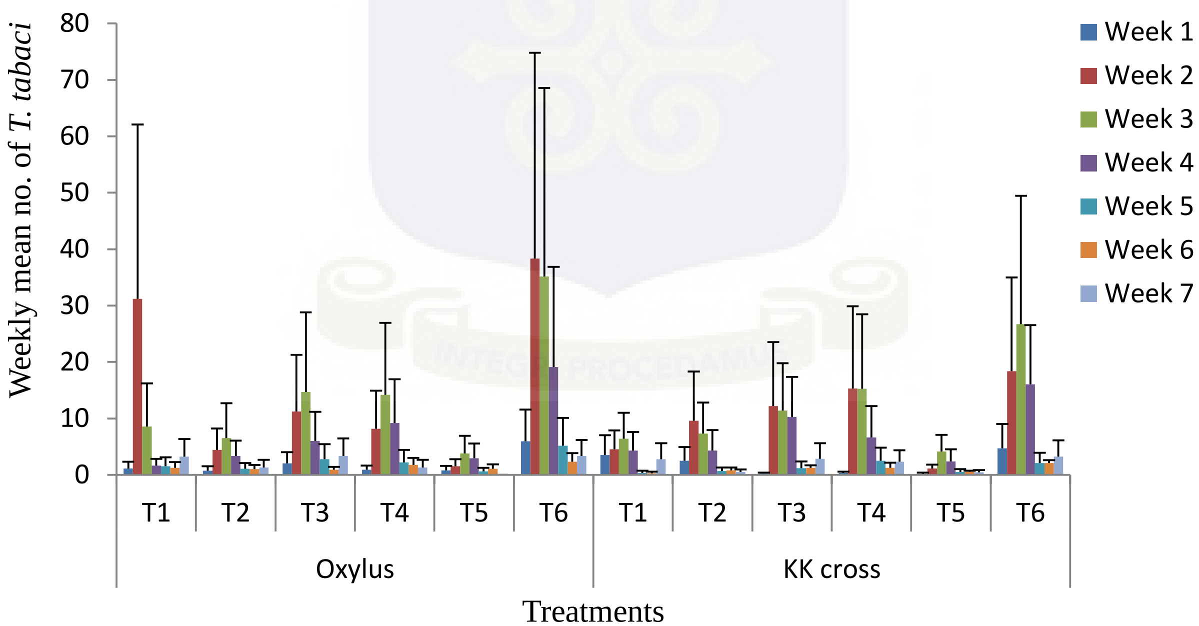


Figure 11: Effects of pest management strategies on mean (±SE) weekly counts of *T. tabaci* per cabbage variety during the minor season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.2.4.3 Variegated grasshopper (*Zonocerus variegatus)*

The population of *Z. variegatus* was generally low throughout the sampling period. Peaks were recorded at the fourth week of sampling. In Bypel 1® and neem treated plots as well as in shallot plots planted 7 days prior cabbage, fewer or no grasshoppers were recorded throughout the sampling period. Meanwhile, the control plots recorded the highest numbers (Figures 12 and 13). There was a significant difference in the number of *Z. variegatus* among the different management strategies for both seasons ($F_{5, 22} = 5.68$, $P = 0.0020$ and $F_{5, 22} = 7.26$, $P = < 0.0010$, respectively). Although Bypel 1® - plots had lower numbers of this pest, the various management strategies did not significantly differ among each other, but were significantly different from the control for the two seasons (Tables 8a and 8b). The effect of varieties did not show any significant differences in the number of *Z. variegatus* sampled in both seasons ($F_{1, 22} = 0.04$, $P = 0.8520$ and $F_{1, 22} = 0.43$, $P = 0.5180$). The interaction between the management strategies and varieties was not significant for the two seasons ($F_{5, 22} = 0.39$, $P = 0.8480$ and $F_{5, 22} = 0.17$, $P = 0.9730$). The weekly sampling had a marginal significant effect on *Z. variegatus* numbers in the major season ($F_{5, 120} = 2.63$, $P = 0.0550$), but was not significant in the minor season ($F_{6, 144} = 3.73$, $P = 0.06$). However, the interaction between the weeks and management strategies was not significant for both seasons ($F_{25, 120} = 1.19$, $P = 0.3000$ and $F_{30, 144} = 1.04$, $P = 0.4280$). The interaction between the weeks of sampling, the management strategy and the varieties were not significant for both season ($F_{25, 120} = 0.80$, $P = 0.6760$ and $F_{30, 144} = 0.72$, $P = 0.8020$). A *t* test also revealed no significant difference between *Z. variegatus* counts for both seasons, though the population was in the minor season ($t_{0.05, 39} = 2.41$, $P = 0.0850$) (appendix 3).

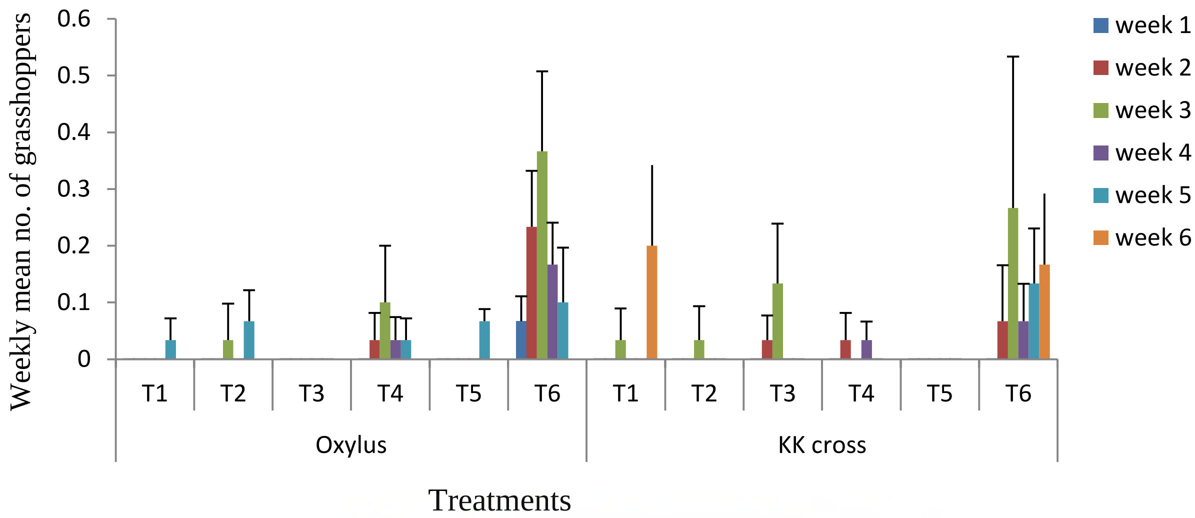


Figure 12: Effects of management strategies on mean (±SE) weekly counts of *Z. variegatus* per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

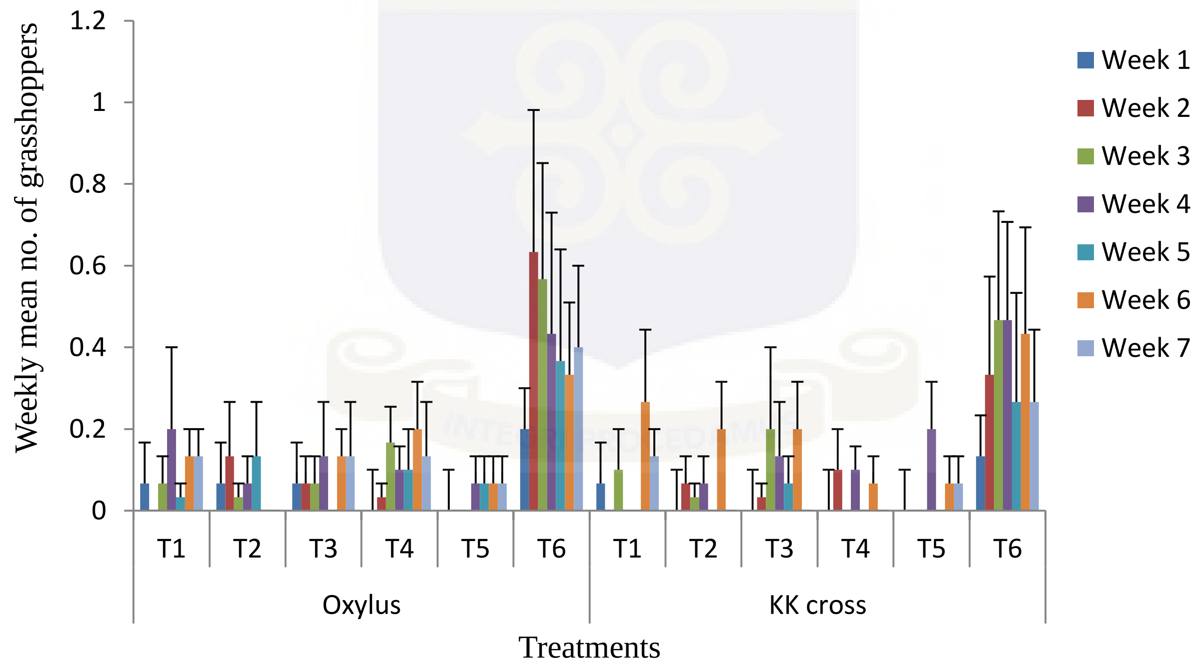


Figure 13: Effect of management strategies on mean (±SE) weekly count of *Z. variegatus* per cabbage variety during the minor season, 2017, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.2.4.4 Plant hoppers

Plant hoppers, *Empoasca* spp. (Hemiptera: Cicadellidae) were spotted in the field and occurred only in the major season. Shallot planted 14 days prior to cabbage recorded fewer hoppers at the fourth week of sampling and the control plots recorded the highest population throughout the sampling period. The rest of the treatments did not record any hoppers (Figure 14). There was no significant difference in the effect of management strategies on plant hoppers numbers for the major season ($F_{5, 22}$ = 1.78, P = 0.1600). The effect of varieties on plant hopper numbers was not significant during the major season ($F_{1, 22}$ = 0.09, P = 0.7660). The interaction between various management strategies and the varieties did not significantly contribute to the number of plant hoppers ($F_{5, 22}$ = 0.09, P = 0.9930). The effect of weeks of sampling on the population of plant hoppers was not significant in the major season ($F_{5, 120}$ = 1.90, P = 0.1650). The interaction between the weeks of sampling and management strategies was not significant for the major season ($F_{25, 120}$ = 1.22, P = 0.3090). The weeks of sampling and varieties equally did not have a significant effect in plant hopper numbers for the major season ($F_{5, 120}$ = 0.67, P = 0.5040). The interaction between the weeks, management strategies and varieties on the number of plant hoppers was also not significant for the major season ($F_{25, 120}$ = 0.67, P = 0.7340).

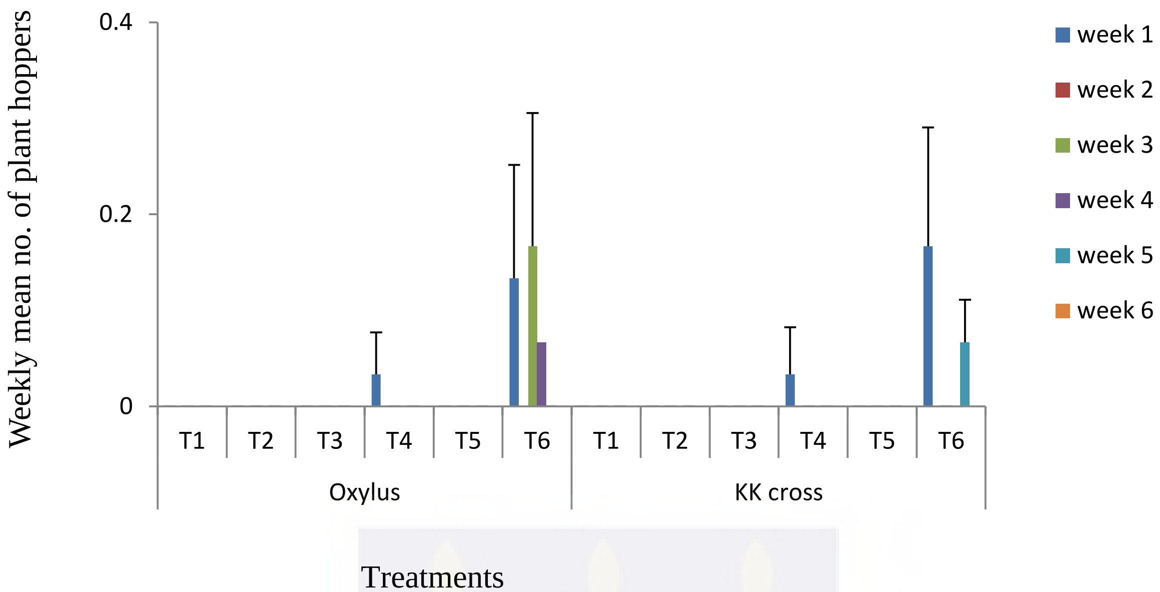


Figure 14: Effects of treatments on mean (±SE) weekly counts of plant hoppers per cabbage variety during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.2.4.5 Trichoplusia ni

Trichoplusia ni was found in the field only in the minor season. Plots treated with aqueous neem seed extract did not record any population of this pest. Bypel 1® and Shallot treated plots had minimal infestation whilst control had the highest infestation level (Figure 15). There was a significant difference in the effect of different management strategies on the population of *T. ni* for the minor season ($F_{5,\ 22}$ = 5.98, P = 0.0010). The different treatments significantly differed from the control but did not differ among each other, although Bypel 1® and neem plots had lower population (Tables 8a and 8b). The cabbage varieties did not have a significant effect on *T. ni* numbers ($F_{1,\ 22}$ = 0.77, P = 0.3910), though oxylus recorded a higher infestation level. The interaction between the varieties and management strategies among the weeks of sampling was not significant for the minor season ($F_{5,\ 22}$ = 0.12, P = 0.9850). The effect of weeks of sampling on the population of *T. ni* was significant ($F_{6,\ 144}$ = 4.06, P = 0.0070). The interaction between the weeks of sampling and management strategies was not significant in the minor season ($F_{30, 144} = 1.13$, $P = 0.3360$). The weeks of sampling and varieties equally did not have a significant effect on *T. ni* population in the minor season ($F_{6, 144} = 0.40$, $P = 0.7870$). The interaction between the sampling weeks, management strategies and varieties on *T. ni* numbers did not significantly contribute to *T. ni* numbers in the minor season (F_{30}, 144 = 0.25, $P = 0.9990$)

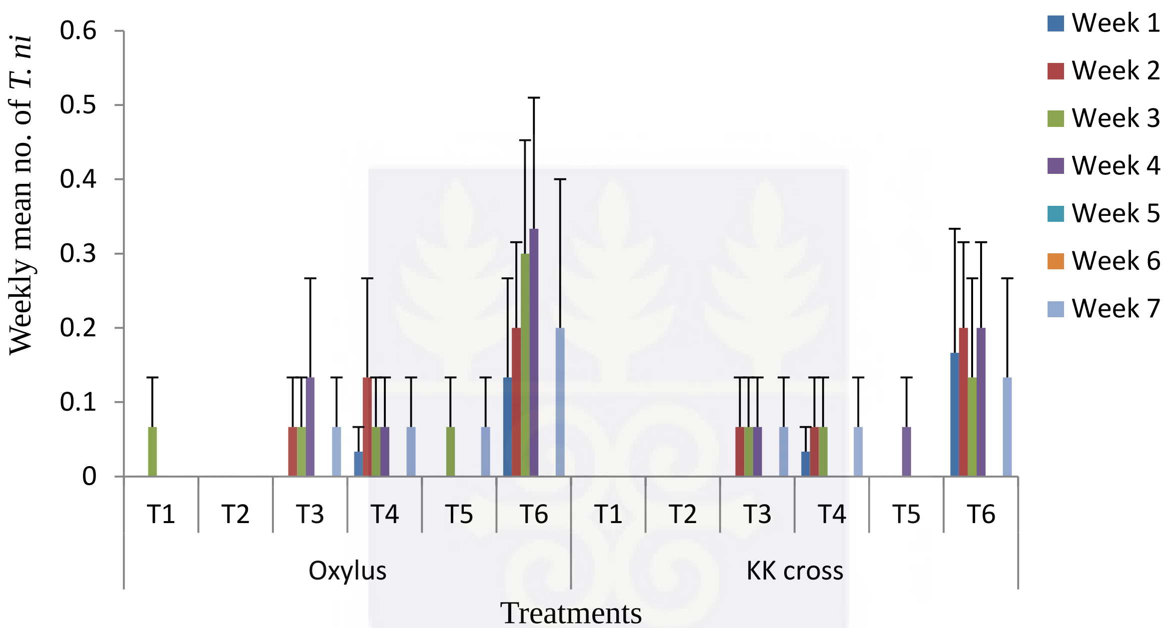


Figure 15: Effects of treatments on mean (±SE) weekly counts of *T. ni* per cabbage variety during the minor season, 2017, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

Table 9a: Effects of six pest management strategies on mean (±SE) weekly counts of different pests during the major season, 2016, in Volta region, Ghana.

		Mean ± S.E				
Treatments		***P. xylostella***	***H. undalis***	***B. brassicae***	***B. Tabaci***	***T. tabaci***
Shallot & aqueous neem seed extract	T1	0.72±0.009b	0.71±0.002b	0.71±0.000b	0.84±0.042c	1.64±0.531b
Aqueous neem seed extract	T2	0.71±0.009b	0.71±0.006b	0.72±0.008b	0.82±0.038c	1.53±0.416b
Shallot planted 7 days Before cabbage.	T3	0.76±0.030b	0.72±0.012b	0.78±0.046a	0.81±0.057c	1.77±0.529b
Shallot planted 14 days before cabbage	T4	0.78±0.047b	0.73±0.020b	0.825±0.083a	0.87±0.062b	1.80±0.536b
Bypel 1® (PrCV+Bt)	T5	0.71±0.006b	0.70±0.000b	0.71±0.006b	0.81±0.030c	1.19±0.229b
Control	T6	0.88±0.062a	0.78±0.035a	0.85±0.070a	0.99±0.053a	2.52±0.886a
Prob.		0.0010	0.0040	0.0210	< 0.0010	0.0220
Lsd (0.05)		0.073	0.035	0.049	0.028	0.7073
F		6.17	4.77	3.35	12.61	3.33

Means with the same letter(s) are not significantly different (P < 0.05, LSD).

Table 9b: Effects of six pest management strategies on mean (±SE) weekly counts of different pests during the minor season, 2017, in Volta region, Ghana.

		Mean ± S.E						
Pest management strategies		***P. xylostella***	***H. undalis***	***B. brassicae***	***B. tabaci***	***Z. variegatus***	***T. tabaci***	***T. ni***
Shallot & aqueous neem seed extract	T1	0.73±0.011c	0.72±0.008b	0.70±0.000c	2.26±0.321c	0.76±0.030b	1.70±0.559b	0.71±0.006b
Aqueous neem seed water extract	T2	0.71±0.011c	0.71±0.007b	0.72±0.008c	2.21±0.428c	0.74±0.027b	1.52±0.416b	0.70±0.001b
Shallot planted 7 days before cabbage	T3	0.78±0.034b	0.73±0.002b	0.78±0.037b	2.57±0.545b	0.76±0.036b	1.89±0.576b	0.73±0.022b
Shallot planted 14 days before cabbage	T4	0.82±0.044b	0.74±0.017b	0.84±0.035b	2.75±0.395b	0.75±0.029b	1.89±0.567b	0.73±0.023b
Bypel 1® (PrCV+Bt)	T5	0.72+0.005c	0.71±0.003b	0.72±0.008c	2.24±0.538c	0.73±0.017b	1.21±0.238b	0.72±0.012b
Control	T6	0.95±0.061a	0.802±0.035a	0.93±0.034a	3.39±0.499a	0.92±0.081a	2.63±0.897a	0.79±0.048a
P		< 0.0010	< 0.0010	0.0030	0.0010	< 0.0010	0.0150	0.0010
F		45.98	9.05	4.89		7.72	3.66	5.98

Means with the same letter(s) are not significantly different (P < 0.05, LSD).

4.3 Effects of different management strategies on the abundance of beneficial arthropods of two cabbage varieties during the major and minor seasons.

The number of ladybird beetles (*Cheilomenes* spp.) started building up at the second week and peaked between the fourth and sixth week of sampling in the major season. There was a significant difference in the number of ladybird beetles as per the pest management strategies in the major season ($F_{5, 22}$ = 2.74, P = 0.0450). In the major season, the population of ladybird beetles was highest on shallot plots planted 14 days prior cabbage which was significantly different from all the other treatments. Fewer numbers of ladybirds occurred on the rest of the treatments except for the control which did not record any number (Table 10). The effect of different varieties did not significantly contribute to ladybird population in the major season ($F_{1, 22}$ = 0.02, P = 0.8760). However, there was no significant difference in the population of ladybird sampled in the major season as per the management strategies and the varieties ($F_{5, 22}$ = 0.81, P = 0.5580).

The spider population was quite high throughout the sampling period occurring on all treatments. Their numbers started building up at the first week and peaked at the sixth week on Bypel 1® and neem treated plots in the major season and on shallot plots planted 7 days prior to cabbage and shallot plots planted the same day, with a short duration neem spray in the minor season. There was no significant difference in the number of spiders among the pest management strategies in the major season ($F_{5, 22}$ = 1.57, P = 0.2090) but the difference was significant in the minor season ($F_{5, 22}$ = 6.00, P = 0.0010). In the minor season, shallot plots planted 14 days before cabbage and shallots planted 7 days before cabbage had the highest ladybird population and did not differ from each other, but differed significantly from the other treatments. The effects of the cabbage varieties did not contribute to a significant difference in the number of spiders sampled in the major season ($F_{1, 22}$ = 0.11, P = 0.7440) but the effect was significant in the minor season ($F_{1, 22}$ = 5.04, P = 0.0350). Oxylus had a significantly higher spider population than the population on KK cross in the minor season. However, the pest management strategies and varieties together was not significant in both seasons for the number of spiders sampled ($F_{5, 22}$ = 2.37, P = 0.0730 and $F_{5, 22}$ = 0.60, P = 0.7030), though higher population was recorded on V_1T_6 (oxylus with no treatment) in the major season and on V_1T_3 (shallot planted 14 days before oxylus) in the minor season.

Hoverflies population started at two weeks and peaks were recorded at the sixth week and fourth week of sampling for both seasons, respectively. Shallot plots planted 14 days prior to cabbage recorded the highest number of hoverflies in the major season. In the minor season, higher hoverfly population was recorded on all shallot treated plots and plots treated with neem seed extract had the lowest numbers (Table 10). There was no significant difference in the number of hoverfly sampled among the management strategies for both seasons ($F_{5, 22}$ = 2.35, P = 0.0750 and $F_{5, 22}$ = 1.37, P = 0.2720). The effect of varieties was not significant for the number of hoverflies for both seasons ($F_{1, 22}$ = 1.06, P = 0.3150 and $F_{1, 22}$ = 0.26, P = 0.6180). The interaction between the different management strategies and the cabbage varieties on the number of hoverflies sampled was not significant for both seasons ($F_{5, 22}$ = 0.38, P = 0.858 and $F_{5, 22}$ = 0.62, P = 0.6890), though higher numbers were found on V_2T_4 (shallot planted 14 days before KK cross) in the major season and on V_1T_6 and V_2T_4 (oxylus with no treatment and shallot planted 14 days before KK cross, respectively) in the minor season.

Cotesia plutellae occurred only in the minor season and its population started at the second week and peaked at the sixth and seventh week of sampling on plots where shallot was planted at 7 days before cabbage. The population was highest on shallot plots planted 14 days before cabbage and lowest on neem-treated and control plots, but there was no significant difference on *C. plutellae* numbers among the pest management strategies in the minor season ($F_{5, 22}$ = 1.71, P = 0.1740). Oxylus had a higher population of this parasitoid than KK cross, but the differences between them was not significant ($F_{1, 22}$ = 0.41, P = 0.5300). Similarly, their interaction was not significant ($F_{5, 22}$ = 0.46, P = 0.7980) but a higher population of *C. plutellae* was found on V_1T_4 (border shallot planted 14 days before oxylus) whilst KK cross with no treatment (V_2T_6) recorded the least numbers.

Table 10: Mean (±SE) number of natural enemies per cabbage plant sampled during the major and minor seasons, 2016/2017, in Volta region, Ghana.

		Mean ± S.E					
		major season			Minor		
Treatment combinations	Cabbage variety	Spider	Hoverfly	ladybird	Spider	Hoverfly	*C. plutellae*
Shallot/cabbage with short neem spray	Oxylus	0.228±0.138	0.017±0.016	0.006±0.004b	0.152±0.055b	0.048±0.038	0.005±0.005
Aqueous neem seed water extract.	Oxylus	0.256±0.160	0.028±0.028	0.006±0.004b	0.133±0.101b	0.010±0.010	0.005±0.005
Shallot planted 7days before cabbage.	Oxylus	0.289±0.060	0.078±0.078	0.022±0.015a	0.285±0.222a	0.057±0.048	0.019±0.019
Shallot planted 14days before cabbage	Oxylus	0.300±0.218	0.139±0.138	0.033±0.033a	0.342±0.224a	0.086±0.086	0.028±0.024
Bypel 1 ®(PrGV+Bt) insecticide.	Oxylus	0.272±0.129	0.017±0.017	-	0.181±0.102b	0.048±0.029	0.009±0.010
Control	Oxylus	0.489±0.227	0.017±0.011	-	0.076±0.057c	0.104±0.105	0.010±0.010
Shallot/cabbage with short neem spray	KK cross	0.306±0.158	0.017+0.017	0.006±0.004b	0.143±0.088b	0.047±0.038	0.004±0.005
Aqueous neem seed water extract.	KK cross	0.356±0.232	0.017±0.017	0.006±0.007b	0.067±0.038c	0.029±0.029	0.005±0.005
Shallot planted 7days before cabbage.	KK cross	0.372±0.192	0.072±0.067	0.006±0.012b	0.162±0.124b	0.067±0.053	0.005±0.005
Shallot planted 14days before cabbage	KK cross	0.189±0.098	0.244±0.213	0.033±0.028a	0.248±0.180a	0.104±0.092	0.029±0.029
Bypel 1 ®(PrGV+Bt) insecticide.	KK cross	0.433±0.230	0.083±0.083	0.022±0.019a	0.114±0.086b	0.038±0.029	0.019±0.019
Control	KK cross	0.278±0.159	0.044±0.030	-	0.095±0.045b	0.009±0.111	-
P		0.4410	0.0720	0.0450	0.0010	0.4280	0.1310
Lsd (0.05)		0.154	0.125	0.021	0.095	0.073	0.023

Means with the same letters are not significantly different (LSD= 0.05).

4.4 Yield assessment

The mean yield (weight, kg) according to the various management strategies in decreasing order was as follows: Bypel 1 ® plots > sole neem > shallot and cabbage combined with a short duration of neem spray > shallot planted 14 days prior cabbage > shallot planted 7 days prior to cabbage > control. There was a significant difference among the mean yield of the pest management treatments in the major and minor seasons ($F_{5, 20}$ = 10.48, P = < 0.0010 and $F_{5, 20}$ = 12.52, P = < 0.0010). In the major season, all treatments had significantly higher yield than the control; plots treated with Bypel 1®, aqueous neem seed extract and shallot/cabbage planted the same with a short duration neem spray had the highest yield and did not differ from each other, but significantly differed from shallot planted 7 and 14 days before cabbage transplanting . In the minor season, aqueous neem seed extract plots, Bypel 1®plots and cabbage plots planted with shallots at the same time with a short duration of neem spray had higher mean yields and did not differ from each other but differed significantly from the rest of the treatments; shallot plots planted 7 and 14days before cabbage and control plots were not significantly different although, shallot planted 14days had higher yield (Table 11). The yield among the cabbage varieties was not significantly different in the major season ($F_{1, 22}$ = 0.07, P = 0.7940), but was significant in the minor season ($F_{1, 22}$ = 11.94, P = 0.0020). Oxylus had significantly higher mean yield (48.96 $\pm$ 2.742 t/ha) than KK cross (41.20 $\pm$ 2.345t/ha) in the minor season. The interaction between pest management strategies and cabbage varieties was not significant for both seasons ($F_{5, 22}$ = 0.89, P = 0.5070 and $F_{5, 22}$ = 0.39, P = 0.8490), where V1T5 (oxylus sprayed with Bypel 1® insecticide) recorded highest yield and V1T6 (sole KK cross) recorded lowest yield in both seasons. The yield was higher in the major than minor season.

Table 11: Mean yield of cabbage heads per treatment combination (t/ha) during the major and minor seasons, 2016/2017, in Volta region, Ghana.

Treatments	Cabbage variety	Mean yield (Tonnes/ha)		t-value	P value
		Major	minor		
Shallot/cabbage with short neem spray	Oxylus	64.12±5.295ab	56.8±1.007a	1.98	0.0490
Aqueous neem seed extract.	Oxylus	64.44±4.155ab	57.87±6.937a	1.02	0.4130
Shallot planted 7days before cabbage.	Oxylus	56.3±3.577b	40.00±3.124b	5.85	< 0.0010
Shallot planted 14days before cabbage	Oxylus	53.33±5.15b	41.87±1.23b	3.1	0.0020
Bypel 1 ®(PrGV+Bt) insecticide.	Oxylus	77.16±5.828a	61.33±4.372a	1.96	0.0510
Control	Oxylus	30.87±5.438c	35.1±1.937c	0.78	0.4350
Shallot/cabbage with short neem spray	KK cross	54.9±6.228b	44.27±6.351b	2.31	0.0220
Aqueous neem seed extract.	KK cross	63.32±5.209ab	46.53±0.933ab	4.32	< 0.0010
Shallot planted 7days before cabbage.	KK cross	60.42±10.251ab	37.07±3.459c	3.88	< 0.0010
Shallot planted 14days before cabbage	KK cross	61.37±5.487a	36.93±4.285c	8.19	0.0010
Bypel 1 ®(PrGV+Bt) insecticide.	KK cross	73.58±7.665a	54.53±3.428a	3.49	0.0010
Control	KK cross	30.67±0.667c	30.7±2.696c	0.43	0.7070
P		< 0.0010	0.0010		
Lsd (0.05)		13.38	8.06		

Means with the same letter(s) are not significantly different (P < 0.05, LSD).

4.4.1 Damage assessment and yield quality

The severity of damage on cabbage leaves and heads on treated plots were lower than on the untreated plots. Damage on plots treated with Bypel 1® and aqueous neem seed extract were within the damage 0 (no damage) and damage 1 (15%) category in the major and minor season, respectively. Shallot planted 7 and 14 days before cabbage recorded a damage category of 1 (15%) and 3 (40-45%), respectively for both seasons. Most of the damages on the untreated plot were within the damage 4 (45-60%) and damage 5(above 60%) for both seasons.

The intensity of damage on the cabbage heads in the context of number of holes led to classification of head quality into marketable and unmarketable heads. There was a significant difference on the percentage of marketable heads among the pest management strategies for both seasons ($F_{5, 20} = 93.00$, $P = < 0.0010$ and $F_{5, 20} = 113.33$, $P = < 0.0010$). All management strategies produced significant higher marketable heads than the control in both seasons (Figures 16 and 17). In the major season, all pest management strategies did not differ from each other but differed significantly from the control. In the minor season, Bypel 1®, neem and shallot combined with a short duration neem spray plots recorded highest percentage of marketable heads and did not differ from each other but significantly differed from shallot planted 7 and 14 days before cabbage in the minor season. The cabbage varieties had no significant effect on the percentage marketable heads produced in the major season ($F_{1, 2} = 2.13$, $P = 0.2810$) but was significant in the minor season ($F_{1, 2} = 12.34$, $P = < 0.0010$). Oxylus produced a significant higher marketable heads than KK cross in the minor season. The interaction between different management strategies and cabbage varieties did not significantly contribute to the percentage marketable heads in the major season ($F_{5, 20} = 0.22$, $P = 0.9520$) but was significant in the minor season ($F_{1, 2}$ = 15.15, P = < 0.0010), where V1T1 (border shallot and oxylus with a short duration of neem spray) and V1T5 (oxylus sprayed with Bypel 1®) recorded the highest percentages and V2T6 (sole KK cross) recorded the least percentage of marketable heads in both season.

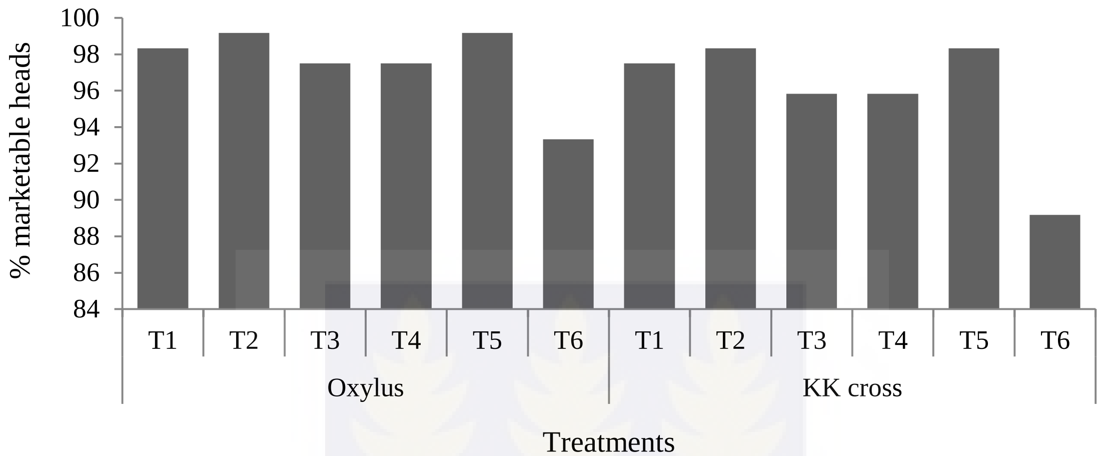


Figure 16: Mean percentage marketable heads for different treatments during the major season, 2016, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

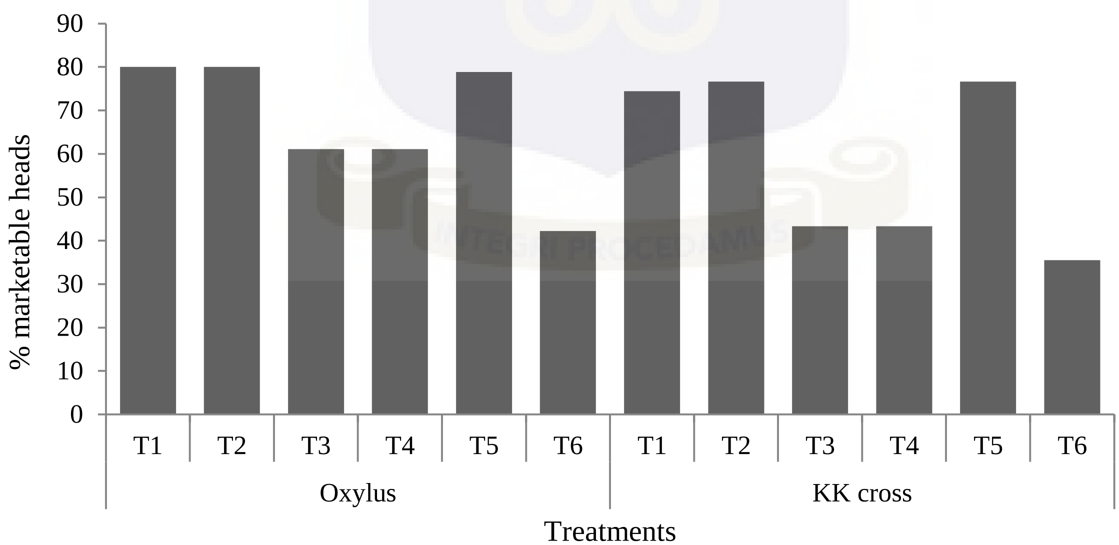


Figure 17: Mean percentage marketable heads for different treatments on Oxylus and KK cross during the minor season, 2017, in Volta region, Ghana.

T_1=Shallot/cabbage planted the same time with short duration of neem spray, T_2=Aqueous neem seed extract, T_3=Shallot planted at 7 days, T_4=Shallot planted at 14 days, T_5=Bypel 1®, T_6=Control.

4.4.2 Multiple heads

The different management strategies differed significantly on the percentage multiple heads formed for both seasons ($F_{5, 20} = 14.19$, $P = < 0.0010$ and $F_{5, 20} = 4.47$, $P = 0.0070$, respectively). Plots treated with Bypel 1®, aqueous neem seed extract and all shallot treatments recorded lower multiple heads as opposed to highest multiple heads in the control plots (Table 12). The effect of cabbage varieties did not significantly contribute to the percentage multiple heads in both seasons ($F_{1, 2} = 1.00$, $P = 0.4230$ and $F_{1, 2} = 0.33$, $P = 0.6220$). The interaction between various management strategies and cabbage varieties was significant in the major season ($F_{5, 20} = 3.10$, $P = 0.031$) but was not significant in the minor season ($F_{5, 20} = 0.33$, $P = 0.6220$). Cabbage plots planted with shallots at the same day, combined with a short duration of neem spray as well as Bypel®1-treated plots recorded the least number of rotten heads whereas, higher rotten heads were recorded in the control plots. KK cross matured 2 weeks before Oxylus and had the highest number of rotten heads for both seasons.

Table 12: Mean number of multiple (%) and rotten heads of cabbage during the major and minor cropping seasons, 2016/2017, in Volta region, Ghana.

		%multiple heads		Rotten heads	
Treatment combination	Cabbage variety	Major	Minor	major	minor
Shallot/cabbage with short neem spray	Oxylus	-	6.667+1.925b	0.667+0.600c	1.333+0.333c
Aqueous neem seed water extract.	Oxylus	2.223+2.22c	6.667+5.093b	1.333+0.013c	2.00+2.000c
Shallot planted 7days before cabbage.	Oxylus	5.553+2.30b	10.003+3.33b	1.00+0.010c	4.000+2000b
Shallot planted 14days before cabbage	Oxylus	1.110+1.00c	10.003+3.33b	1.00+0.010c	2.333+2.333b
Bypel 1 ®(PrGV+Bt) insecticide.	Oxylus	-	5.553+4.846b	0.667+0.600c	1.333+0.333c
Control	Oxylus	7.780+1.11a	14.32+1.925a	5.00+2.00c	6.667+1.667a
Shallot/cabbage with short neem spray	KK cross	3.333+3.0b	6.667+1.113b	0.667+0.600a	2.000+0.001c
Aqueous neem seed water extract.	KK cross	4.443+1.11b	4.443+4.443c	2.00+0.200c	2.000+1.000c
Shallot planted 7days before cabbage.	KK cross	2.223+2.10c	11.113+1.11b	3.333+2.33b	3.000+0.01b
Shallot planted 14days before cabbage	KK cross	-	7.78+1.11b	3.501+1.667b	1.000+1.00c
Bypel 1 ®(PrGV+Bt) insecticide.	KK cross	-	7.78+1.11b	0.667+0.060c	2.667+0.333b
Control	KK cross	8.89+2.22a	18.88+7.766a	4.667+2.667a	7.000+1.00a
P		0.0010	0.0070	< 0.0010	0.0010
Lsd (0.05)		2.468	5.714	1.447	1.596

Means with the same letter(s) are not significantly different ($P < 0.05$, LSD).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of various pest management strategies on insect fauna on two cabbage varieties during the major and minor cropping seasons.

The findings from this research have demonstrated that, the production of cabbage in the Ketu South municipality of the Volta region of Ghana is affected by numerous insect pests such as cabbage aphids (*B. brassicae*), DBM (*P. xylostella*), cabbage webworm (*H. undalis*), variegated grasshopper (*Z. variegatus*), cabbage looper (*Trichoplusia ni*), whiteflies (*B. tabaci*), which are all earlier recorded pests of cabbage found in Ghana (Obeng-Ofori *et al*., 2007; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014, 2016). Additionally, the onion thrips, *T. tabaci,* reported as an important pest of cabbage (Sirrine and Lowe, 1894) was equally found in the study area.

Insect pests sampled on the cabbage field in the major season were lower compared to those that were present in the minor season, a finding supported by Yaseen (1974) who reported higher pest populations during periods of low rainfall in Trinidad. The reason may be due to the dominance of the natural enemies such as predators and parasites that fed on them and natural elements such as heavy rainfall, which washed off the eggs, larvae, pupae and adults to destruction. 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.

5.2 Effects of treatments on the population of key insect pests of two cabbage varieties during the major and minor season.

The numbers of *P. xylostella, H. undalis* and *B. brassicae* kept increasing and the weekly sampling showed significant differences in their numbers for the two seasons. This is because as the cabbage grew, new succulent leaves sprouted which provided room to accommodate more pest numbers on the plant. The study showed that Bypel 1® effectively controlled the major insect pests of cabbage, *P. xylostella, H. undalis*, and *B. brassicae* for both seasons. Li and Segonca (2003) observed high efficacy of GCSC-BtA (Germany-China Scientific Cooperation - *Bacillus thuringiensis* - Abamectin) biocide on key cabbage pests whilst Paul *et al.* (1997) in a similar study, reported that products containing effective strains of *B. thuringiensis* can be successfully used to manage *P. xylostella. Bacillus thuriengensis* produces a toxin that causes paralysis of an insect digestive tract (Guerena, 2006). This toxin breaks down the gut wall allowing spores to invade the insect's body and the insect ceases to feed, and consequently dies by starvation, septicemia and/or osmotic shock within 24 to 48 hours (Rowell and Bessin, 2005), leading to decrease in pest numbers. Caterpillars in their early stages of development are more susceptible to this toxin, whereas, older and bigger worms are harder to kill (Guerena, 2006). However, the effect in this study is more synergistic since all stages were effectively killed. Bypel 1® (PrGV+Bt) is a mixture of *Pieris rapae* granulosis virus and *Bacillus thuriengensis* used as a natural biopesticide and this study was the first to document its effectiveness against cabbage pests in the Ketu South municipality.

Aqueous neem seed extract did not significantly differ from Bypel 1® in terms of its effectiveness and significantly reduced *P. xylostella* and *H. undalis* numbers during the sampling period. Aqueous neem seed extract has been shown to have detrimental effects on many pests. For instance, work by Obeng-Ofori (2008) using crude seed extracts of neem was effective against insect pests of tomato, cabbage, cucumber, okra, pepper and garden eggs. According to Lidet *et al*. (2007) and Sow *et al*. (2013), effective control of *P. xylostella* was achieved when neem was used as treatment on cabbage. Prasannakumar *et al*. 2014 recorded effective control of *H. undalis* and aphids when cabbages were treated with neem seed powder extract and neem soap. The extracts of *Azadirachta indica* have been successfully used to control infestations of cabbage aphids, other key pests (Rando *et al*., 2011; Kibrom *et al*., 2012; Ezena *et al*., 2016; Forchibe, 2016; Forchibe *et al* in press) and cowpea pests (Afreh-Nuamah *et al*., 2006). Neem is a botanical that has been recognized for its repellent, oviposition deterrent and natural insecticidal properties as explained by Saxena *et al*., 1988. It is a potent anti-feedant and has a strong disrupting effect on growth and development of several species of insect (Schmutterer, 1990). It appears in this study that its effect was more of the anti-feeding which decreased feeding activity after the neem extract was applied. Nowadays, the adverse effects of synthetic insecticides call for the development of new ones, such as Bypel 1® and Neem insecticides that are toxic only to the target pest (Liu *et al*., 1999). The effectiveness of Bypel 1® followed by aqueous neem seed extract in the study indicates their usefulness in controlling insect pests when incorporated into Integrated Pest Management (IPM).

The shallot treatments were not statistically different from Bypel 1® and neem treatments in terms of effectiveness in reducing *H. undalis* numbers in both seasons, *P. xylostella* numbers in the major season but differed in effectiveness on *P. xylostella* in the minor season respectively, with the control recording the highest numbers. This suggests that the repellant properties of shallots were as effective as the insecticidal property of Bypel 1® and neem extract as reported by Mandumbu *et al*., (2014) who recorded no significant differences in pest population between intercropped and chemically treated cabbages. In similar studies, cabbage plants intercropped with other non-hosts recorded significantly lower populations of DBM due to the confusing olfactory and visual cues received (Srinivasan and Krishna, 1992; Said and Itulya., 2003; Asare-Bediako *et al*., 2010). Shallot is in the Allium family and as a border crop created a physical barrier to the movement of insect pests which disrupted the visual and olfactory cues between the insects and the cabbage as explained by Vandemeer, 1989 and Asare- Bediako *et al*., 2010. This makes the pests ineffective in their feeding and egg laying, causing the natural enemies to increase in number to effectively manage the insect pests. More so, these plants release strong volatiles (allyl-propenyl-disulphide) which reduce the attraction of phytophagous insects, alter host-finding behaviours, deter or stimulate some insects' olfactory organs (Nottingham, 1987; Renwick, 1999; Said and Itulya, 2003; Calvo-Gómez *et al*., 2004) and therefore making the use of repellent crops in intercropping a plausible approach for future pest control.

Shallots planted the same day with cabbage combined with a short duration of neem spray gave effective control of all pests sampled, especially *B. brassicae*. Oseifuah (2015) recorded a reduction in key cabbage pests from the fourth sampling week when onion was intercropped with cabbages, both planted the same day, but recommended a short duration spray to sufficiently control key pests at the initial stage. In this study, the short neem spray was able to suppress pest population at the early stages of the crops and subsequently, shallot plants had accumulated sufficient foliage and repellent properties on leaves to offer a synergistic effect to repel the pests. The effectiveness of non-host plants is dependent on sufficient repellent properties which accumulates as leaves develops, implying that the timing of planting is crucial as indicated by

Shankar *et al*., 2005 and Lü and Liu, 2008. Trials conducted in India showed that planting a row of tomato 30 days before cauliflower significantly reduced the incidence of *P. xylostella* (Kandoria *et al*., 1999) whilst Hasheela *et al*. (2010) in a similar study showed reduced *P. xylostella* numbers on cabbage borded with Indian mustard which was planted 15 days prior to cabbage transplanting. In the current study, Shallot planted 14 days was superior to that planted 7 days before cabbage and efficiently reduced *P. xylostella* and *H. undalis* populations. Shallot plants had produced enough foliage to release chemicals that sufficiently repelled the pests since they were planted earlier before cabbages. The significantly higher pest numbers recorded for the unprotected cabbage plants compared with the protected ones is an indication of the effectiveness of the various pest management practices used in protecting the cabbage as was also found by Andow, 1991; Asare-Bediako *et al*., 2010; Hasheela *et al*., 2010; Ahmad and Ansari, 2013; Katsaruware and Dubiwa, 2014. Generally, intercropping system houses a greater diversity of insects, reduce pest populations and deter insect attraction to host plants (Finch and Collier, 2000; Andow, 1991; Hooks and Johnson, 2003; Cai *et al*., 2007, 2010; Hasheela *et al*., 2010; Katsaruware and Dubiwa, 2014), as opposed to monocropping, where, higher concentration of host plants provides more resources for exploitation by the pests, thereby boosting their population density (Abate *et al*., 2000).

However, although planting shallot 14 days before cabbage had lower *B. brassicae* numbers than shallot planted at 7 days, both were not statistically different from the control (sole cabbage) in the major season. Earlier works by Shanker *et al*. (2007) stated that intercropping cabbage with non-host plants effectively controlled aphids on cabbage. In this study however, control by intercropping alone was inadequate to control this pest during the major season and the reason may be due to the fact that a given pest may show variable responses over space and time (Risch *et al*., 1983). Helenius. (1998), stated that intercropping does not necessarily guarantee the reduction of the impact of the pests. Mochiah *et al*. (2011) recorded no significant differences in pest population between control plots and cabbage- tomato intercrops. None of the 54 crops tested for their usefulness in intercropping in Taiwan had any significant impact on cabbage pests especially aphids (AVRDC, 1987). Though there was no significant difference between the shallot treatments and the control, the lower numbers of *B. brassicae* found on shallot plots than the control over the sampling weeks can be appreciated to be a sign of intercrop potentially being able to control their numbers over a long period of time than in a short term (Cai *et al*., 2011).

The cabbage variety, oxylus had lower populations of *P. xylostella* and *H. undalis*, but had a higher aphid population though differences were not significant for both seasons. It appears that the ability of oxylus to host low *P. xylostella* numbers is based on leaf texture since oxylus leaf epidermis is relatively thicker compared to those of KK cross which may hinder mining activities by early instar larvae. KK cross had the least numbers of aphids supporting findings by Lal (1989) that started that KK cross supported less aphid infestation and is a moderately resistant cultivar. KK cross is early maturing and matured two weeks before oxylus, but farmers in Ketu South and other regions in Ghana rely on the cultivation of oxylus cabbage variety because of its compact head and consumer preference. The lack of significant differences in the population of major pest sampled is indicative that, both varieties did not respond differently to the various pest management strategies.

5.3 Other pests

Reduction of pest populations has been reported after application of different treatments by other scientists. Sow *et al*. (2013) recorded lower pest populations with no significant differences between neem plots, biobit (*B. thuriengensis*) and neem/biobit rotated plots. Work by McEwen and Hervey, 1958, 1959 showed high efficacy of the polyhedrosis virus against the cabbage looper. The result of this study shows that Bypel 1® significantly reduced the population of *B. tabaci, T. tabaci, Z. variegatus and T. nii* in both seasons. This was directly followed by aqueous neem seed extract since no significant differences were observed between the pest numbers in neem and Bypel 1® - treated plots. The effective control of these insects can be attributed to the synergistic effect of *Pieris rapae* granulosis virus and *Bacillus thuriengensis* found in Bypel 1® and to the diverse modes of action of azadirachtin present in neem. It could also be that, neem acts as a deterrent when sprayed to plants and also alters some properties of the cabbage plant such as the leave colour that attracts these insect pests, thus, deterring them. This is in line with the light-green, instead of the normal green colour of cabbages observed on neem plots during this study and agrees with Heinrich Schmutterer in 1952, who recorded the desert locust (*Schistocerca gregaria* (Forskal)) refusing to feed on neem. Appiagyei (2010) reported that whiteflies were more susceptible to neem extracts than to karate (lambda-cyhalothrin). Eziah (1999) reported the efficacy of neem seed extract against *Thrips palmi.*

Shallot- treated plots also significantly reduced *T. tabaci*, *T. ni*, and *Z. variegatus* numbers and were not significantly different from plots sprayed with the two biopesticides. Kirtikar and Basu (1975) stated that Allium spp. have strong pungent repelling action against numerous pests whilst Simmonds *et al*. (1992) reported that Allium spp. are very effective antifeedant. The lack of significant differences in pest numbers indicated that the shallot treatments were as effective as the bioinsecticides in controlling these pests which lends support to findings by Mandumbu *et al*., (2014). Border shallots planted with cabbages on the same day combined with a short duration of neem spray recorded consistently least numbers of these pests, followed by shallot planted 14 days before cabbage, and finally shallot planted 7 days before cabbage. This shows the relative effectiveness of shallot plant odours over time, especially where pest populations were consistently lower after neem application was stopped in T1, indicating the repellant effects produced by the shallots over time. However, plots treated with biopesticides and shallot/cabbage plots with a short duration of neem spray had a significantly lower *B. tabaci* population indicating their superiority to border shallot planted 14 and 7 days before cabbage. The control recorded a significant higher population of all pest sampled in both seasons and this attests that population explosion of pests may occur in monocultures with a narrow genetic base. The cabbage variety, oxylus recorded higher population of *T. tabaci*, *Z. variegatus* and plant hoppers than KK cross though the differences were not significant, but with a significant higher population of *B. tabaci* throughout the sampling period. Oxylus is susceptible to insect pest infestation (Per. Comm. Ken O. Fening) and cabbage heads with tightly packed leaves leads to higher thrips populations presumably because the insects are sheltered against predators (Voorrips, 2008). In this study, oxylus was more susceptible to some insect pest infestation and the higher pest numbers could be attributed to the compact nature of its heads which prevented the pests from predators. Generally, pest species occurred earlier on KK cross throughout the sampling period due to the vigorous vegetative growth at the initial stage since it’s an early maturing variety.

5.4 Effects of different treatments on the abundance of beneficial arthropods of two cabbage varieties during the major and minor seasons.

Beneficial insects that were observed in the field included spiders, hoverflies, Braconid parasitoid of DBM, *Cotesia plutellae*, ladybird beetles, and black ants. This study's data suggested that Bypel 1® and aqueous neem seed extract treated plots had no or minimal detrimental effect on natural enemies of pests. Several studies on biopesticides (Navon, 2000; Owusu-Ansah *et al*., 2001; Obeng-Ofori and Ankrah, 2002), clearly indicate no effect of biopesticides on natural enemies of insect pest. Similarly, Rowell and Bessin (2005) noted that *B. thuringiensis* was not harmful to the diamondback moth parasitoid, *Diadegma* sp. Other studies also reported that, Neem oil formulation was effective against *L. erysimi* and did not have any detrimental effect on its hoverfly predator, *Ischiodon scutellaris*; (Boopathi and Pathak, 2011). However, low populations of natural enemies such as hoverflies and ladybird beetles recorded on Bypel® and neem treatments was due to lower populations of particular pests such as aphids, DBM after these treatments were applied. Spiders, being generalist predators on the other hand were high in all treatment plots including Bypel 1®, neem and control plots because of the availability of other sources of prey as explained by Forchibe, 2016. This confirms that the Bypel 1® and neem treatments only had a minimal effect on the natural enemies, including the ladybirds and hoverflies.

The planting time of the repellent crop in this study significantly contributed to the abundance of natural enemies through a reduction of various pests. Shallot planted 14 days before cabbage had a significant higher spider population than all other treatments. Previous studies on intercropping especially those using allium family as pest repellents demonstrated that, this approach is environmentally friendly (Katsaruware and Dubiwa, 2014) and enhance natural enemy presence (Luchen, 2001; Asare- Badiako *et al*., 2010; Katsaruware and Dubiwa, 2014). Similarly, Hooks and Johnson (2003) noted high population of natural enemies in intercropped plants. Shankar *et al*. (2005) suggested that timing of planting could provide effective means for reducing diamondback numbers, damage and increase natural enemies whilst Lü and Liu. (2008) indicated that, appropriate planting time enhance natural enemy presence. *Cotesia plutellae* was observed in the field only during the minor season and its population was highest on shallot plots planted at 7 days and control plots. Earlier work by Cobblah *et al*. (2012) had high numbers of this parasitoid in the major and minor seasons. However, her work was conducted in three seasons (dry season, minor rainy season and major rainy season) with different environmental and climatic conditions. In a study by Oseifuah (2015), she did not observe *C. plutellae* on her research field at Kpong during the dry season. This parasitoid is a K strategy insect and its numbers in the major season lagged behind that of its host, *P. xylostella*. Its presence in the minor season contributed to a reduction in *P. xylostella* numbers but Hu *et al*. (1997) explained that using *C. plutellae* alone to control *P. xylostella* in the field may not be very effective due to the poor search-ability of the parasitoid in finding its prey. However, complementing its effect with other environmentally friendly control interventions like biopesticides and cultural control such as companion planting will offer a better protection of the crop.

5.5 Effect of different treatments on the yield and quality of two cabbage varieties during the major and minor seasons.

According to the current study, the highest yield was recorded in plots treated with the Bypel 1® insecticide. The aqueous neem seed extract treatments produced the second highest yield and were not significantly different from that of Bypel 1® plots. Sow *et al*. (2013) observed an increase in head size due to effective control of *P. xylostella* when neem, biobit® (*B. thuringiensis*) and neem/biobit® rotated was used as a treatment on cabbage, with no significant differences between them. Pedigo (1999) indicated that natural enemies play a role in reducing the damage potential of significant pests with a resultant increase in yields. The larger head weights recorded in biopesticides plots could be attributed to lower pest populations found on these treatments.

Intercropping in some instances, results in loss of weight in vegetable plantings (Theunissen *et al.*, 1995). However, intercropping in the current study, resulted in increased weight in cabbage. Yield (tonnes/hectare) from shallot plots sprayed with short duration neem was similar to that on Bypel 1® and neem plots but significantly differed from shallot plots planted 7 and 14 days before cabbage transplanting in the major season. Mandumbu *et al*. (2014) noted that cabbage yield in intercrop plots were similar to that achieved in chemically- treated plots. According to Cerruti *et al*. (2002), any increase in quality due to intercropping must be sufficient to compensate for lower number of heads or intercropping systems may only be practicable in systems where quality is of greatest importance. In the current study it was observed that shallots released sufficient odours that led to a reduction of pests numbers, and hence an increase in yield was recorded compared with the control (sole cabbage). Also, the high natural enemy presence (spiders, ladybirds and hoverflies) offered natural control that led to increased yields. Oxylus produced medium seized heads with higher weights as opposed to KK cross with larger heads, but differences were not significant. This could be attributed to the compact nature of oxylus heads, with well-arranged wrapper leaves. Among the interaction between different management strategies and cabbage varietal resistance, oxylus which was treated with Bypel 1® (V1T5) produced the highest mean yield whilst KK cross with no treatment (V1T5) produced the lowest yield. This interaction indicates that cultivar resistance and management strategies could be adopted by cabbage farmers to produce higher yields with a resultant higher economic return.

Damage was lowest on Bypel 1® and neem treatments resulting in highest quality marketable heads than other treatments in both seasons. A similar finding by Lidet *et al*. (2009) and Sow *et al*. (2013) reported improved cabbage yield and quality when neem and products containing *B. thuringiensis* were used against insect pests on cabbage. These treatments were able to suppress pests' population leading to increase head quality in this study. Shallots planted at 14 days followed by 7 days before cabbage had less head damage than the control and produced a significant higher marketable heads in the major season than in the minor season. Despite the higher pest numbers on oxylus, it recorded less damage and a higher percent marketable heads than KK cross. This is because oxylus leave texture was harder and more fibrous than KK cross leaves that prevents early instars from mining the leaves implying it could be a tolerant variety. Oxylus and KK cross planted with shallot with a short duration of neem spray, oxylus treated with Bypel 1® and KK cross treated with neem produced higher marketable heads than other treatments implying that, even with the partial resistance or tolerance, fewer applications of the biopesticide or the botanical can effectively increase marketable heads while suppressing pest pressures and their associated damage.

Percentage multiple head formation was significant between the treatments for the two seasons, where most cabbage plants in untreated plots developed several, multiple heads due to the damage of apical growing points that occurred to the plants during early vegetative development. The least percentage was observed in the neem plots, and this is in line with findings that reported improved yield when neem was used as a treatment on cabbage (Baidoo and Adam, 2012; Sow *et al*., 2013; Ezena *et al*., 2016; Forchibe, 2016). The presence of a significant interaction between the different treatments and cabbage varieties in the percentage multiple heads indicates their usefulness in IPM.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Cabbage is one of the most difficult crops to grow and sell particularly in Africa, due to heavy physical damages that occur on the leaves which discourage consumers. On the other hand, the over reliance and non-judicious use of synthetic insecticides by cabbage farmers can compromise the quality of cabbages and also increase the production cost. Conservation Agriculture practices has the potential to improve crop yields, while improving the long-term environmental and financial sustainability of farming. The study showed that by using biopesticide, botanical and by determining the optimum planting time of repellent crops in intercropping, it is possible to achieve an efficient biological control against pests and to produce safe cabbage crops.

The biopesticide and the botanical efficiently managed insect pests on cabbage, while conserving their natural enemies. The effect of Bype1® insecticide surpassed that of the other treatments, leading to higher yields and percentage of marketable heads as opposed to the control. Bype1® effectiveness was directly followed by aqueous neem seed extract, since both were not different statistically. This therefore reveals that Bype1® insecticide and aqueous neem seed extract are effective options for the management of insect pests on cabbage.

A conservative approach based on companion planting through intercropping, using pest repellent plants has potentially direct effects on pests (such as repellent, toxic, masking host plant odours, and masking visual orientation), or indirect effect (such as stimulating natural enemies and inducing resistance in host plant). Border shallot planted the same day with cabbage combined with a short duration of aqueous neem seed extract spray effectively controlled both key and minor pests, leading to higher weights and marketable heads in both seasons, indicating its usefulness in conservation agriculture. Apart from aphids, the other shallot treatments demonstrated their potential in the management of cabbage pests while maintaining ecological balance with natural enemies. In conservation agriculture, insect pests are held in check by an abundant and diverse community of beneficial organisms. Since the demand for organically produced food is on the increase, the non-pesticide management of crops is becoming popular among vegetable farmers which minimize cultivation costs and avoid dependency on manufactured inputs. This offers a better control option since shallot is readily available in the Ketu South, asides its marketable value when used as a border crop.

From the study, no cabbage variety was entirely immune to pest attack, but both possessed some partial resistance or tolerance to these insect pests. Even a cultivar with partial resistance or tolerance can be utilised in the integrated pest management programmes as it will require less insecticidal protection. Finally, the existence of significant interactions suggest the potential success of combining different management strategies as means to safely manage pest problems on these two popular cabbage varieties in the field to some extent.

6.2 RECOMMENDATIONS

It is recommended that biopesticides (Bypel 1®) and botanicals (Neem) should be used as an alternative to synthetic insecticides for effective management of insect pests, and also for environmental and food safety purposes. The repellent properties of shallot alone could be sufficient to manage some cabbage pests but, should be combined with other control options such as biopesticides, botanicals, plant resistance or tolerant varieties to efficiently manage insect pests in the field. It is recommended to have shallot plants planted earlier than the main crop since plant odour is increased as leaves develop. Similar work should be carried out in other regions to enable location - specific interventions to be developed and to establish optimum planting time for other repellent crops so as to boost vegetable farming.

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APPENDICES

Appendix 1: Mean population of different pests sampled on two cabbage varieties in the major season, 2016.

		Mean + S.E			
Cabbage variety	*P. xylostella*	*H. undalis*	*B. brassicae*	*B. Tabaci*	*T. tabaci*
Oxyllus	0.753±0.020	0.723±0.013	0.76±0.025	0.8787a	1.746+0.349
KK cross	0.772±0.015	0.730±0.014	0.77±0.035	0.8362b	1.737+0.294
F	0.84	0.44	0.31	0.014	0.00
P	0.3690	0.5120	0.583	0.0020	0.966
Lsd (0.05)	0.0422	0.0204	0.028	0.0159	0.408

Means with the same letter(s) are not significantly different (P < 0.05, LSD).

Appendix 2: Mean population of different pests sampled on two cabbage varieties in the minor season, 2017.

Cabbage variety	*P. xylostella*	*H. undalis*	*B. brassicae*	*B. tabaci*	*Z. variegatus*	*T. tabaci*	*T. nii*
Oxyllus	0.77±0.027	0.7351+0.015	0.77±0.031	3.01±0.264b	0.79±0.030	1.83±0.368	0.74±0.015
KK cross	0.79±0.03	0.7322+0.016	0.79±0.040	2.11±0.171a	0.77±0.027	1.78±0.303	0.73+0.012
F	2.5	0.11	0.65	75.52	0.53	0.07	0.77
P	0.1280	0.7470	0.4280	< .0010	0.4760	0.7870	0.3910

Means with the same letter(s) are not significantly different (P < 0.05, LSD).

Appendix 3: Differences between insect numbers for the major and minor season (t-test)

Insects	Major	minor	t value	p
Plutella xylostella	0.093±0.026	0.34±0.093	3.05	0.0040
Hellula undalis	0.004±0.010	0.136±0.096	2.04	0.0510
B. tabaci	0.262±0.031	11.44±0.395	28.19	< 0.0010
T. tabaci	5.66±1.610	21.50±0.970	8.41	< 0.0010
Z. variegatus	0.0352±0.012	0.394±0.149	2.41	0.0850
Spiders	0.314±0.030	0.274±0.073	-0.5	0.6180
Hoverfly	0.015±0.021	0.125±0.087	0.67	0.5070

Appendix 4. Some insects found on the field during the sampling period.



DBM larvae

DBM adult

H. undalis (larvae)

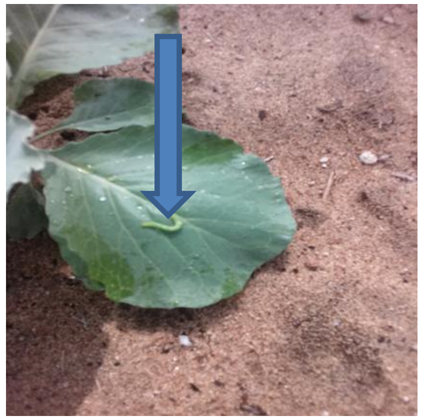
Whitefly

Estigmene spp (larvae)



Grasshoppers

Snails on cabbage



T. ni

Disease transmitted by aphids

Rotten head

Multiple heads

parasitized larvae

Taylor ant

Cheilomenes lunata

C. plutellae (larvae and pupa)

Predatory ant