POTENTIAL OF SOME BOTANICAL EXTRACTS, SOAP SOLUTIONS AND COMPANION PLANTS AGAINST CABBAGE APHID ("BREVICORYNE BRASSICAE L.") ON RAPE ("BRASSICA NAPUS L.")

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(CROP PROTECTION)

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POTENTIAL OF SOME BOTANICAL EXTRACTS, SOAP SOLUTIONS AND COMPANION PLANTS AGAINST CABBAGE APHID (*Brevicoryne brassicae L.*) ON RAPE (*Brassica napus L.*)

A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science (MSc) in Crop Science (Crop protection)

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STATEMENT OF ORIGINALITY

This research and all experiments were done by me, with a complete dissertation written by me between December 2017 and July 2018. I submitted this dissertation for Master of Science Degree Crop Protection at the Botswana University of Agriculture and Natural Resources. It is original except where references were made, and the dissertation has not been submitted before for any diploma or degree in any other University.

Signature: ....

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DEDICATION

I dedicate this work to my loving parents Mr Lentswenyane Mochibidu and Mrs Kebogile Mochibidu who always put my education first and continue to support me, my husband Shahzad and my children Wali and Kiran for their utmost support and motivation which kept me going throughout my research days. I thank you.

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ABSTRACT

Rape (*Brassica napus* L.) is a popular leafy vegetable grown for home consumption and for sale in Botswana and other African countries. It significantly contributes to the livelihood of both smallholder and commercial farmers. Cabbage aphid (*Brevicoryne brassicae* L.) is one of the most important sap sucking pests of Brassica crops in Botswana, and if not controlled, can cause yield losses of rape and other brassicas. There is public concern related to pesticides use in crop production and this has led to the rise of consumer interest in organically produced foods. Net-shade and field experiments were conducted at the Botswana University of Agriculture and Natural Resources, Gaborone to test the potential of some botanical extracts, soap solutions and companion plants against cabbage aphid (*Brevicoryne Brassicae L.*) on rape (*Brassica Napus L.*) to determine the (i) effect of spraying water-based botanical extracts and soap solutions on mortality of cabbage aphid on rape; (ii) the effect of companion planting rape with garlic (*Allium sativum* L.), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes patula* L.), basil (*Ocimum basilicum L.*) and imidachloprid application on cabbage aphid populations and yield of rape. In the net-shade study, water-based botanical extracts of garlic, peppermint, French marigold, and basil at10% and 20% (fresh w/v) concentrations and 5% and 10% (v/v) liquid soap solutions were sprayed against cabbage aphid on rape plants in insect-proof cages. The results of the net-shade study indicated significantly higher aphid mortality in summer than winter (P=0.0001) and imidacloprid had the highest mortality followed by 10% liquid soap, 20% basil and garlic, marigold and mint. In the field experiment, imidacloprid spray significantly controlled the aphid populations (P=0.0001) compared to the companion plating treatments. Among the companion planting treatments, basil had the lowest aphid population followed by marigold, mint, garlic and the untreated control which had the highest population. Therefore, spraying rape with water-based extracts of basil and marigold and liquid soap has the potential to control cabbage aphids in place of synthetic insecticides. This study, therefore, has shown that botanical can be incorporated as constituents of a pest management strategy. More so, smallholder farm producers who cannot afford expensive and dangerous synthetic insecticides can utilize basil and marigold for pest management, in addition to selling these herbs for profit.

ACRONYMS/ ABBREVIATIONS

ANOVA – Analysis of variance

BUAN – Botswana University of Agriculture and Natural Resources

CEDA – Citizen Entrepreneurial Development Agency

CM – Centimetre

DMS – Department of Meteorological Services

FAP – Financial Assistance Policy

F - Family

Fig - Figure

GDP – Gross Domestic Products

Ha – Hectare

HSP – Horticulture Enterprise Support Programme

ISPAAD – Integrated Support Programme for Arable Agriculture Development

Kg – Kilogram

L – Linnaeus

LSD – Least Significant Difference

M - Metre

M^2 - Metre squared

Mm – millimetres

MoA – Ministry of Agriculture Development and Food Security

RCBD – Randomized Complete Block Design

US EPA Pesticides – United State Environmental Protection Agency

SSKIA – Sir Seretse Khama International Airport

Spp - Species

T. minuta –Tagetes minuta

Tons – Tonnage

Var - variety

^0C – Degrees Celsius

% - Percentage

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CHAPTER 1.0 INTRODUCTION

1.1 Agriculture in Botswana

The vegetable industry is still at an infant stage in Botswana; however, it has a great potential for growth because there is a high demand for vegetables. Botswana's agriculture sector accounts for 2.7 % of the country's gross domestic product (GDP). The horticulture sector's output is reported to account for 0.1 % of (GDP) (Chatterji et al., 2015). The horticultural sector is of importance to Botswana with respect to providing food security and could potentially be a significant contributor to economic diversification drive led by ministry of investment, trade and industry (Chatterji et al., 2015). The MoA (2015) reported that even though there has been a substantial increase in national demand of horticultural products over the last decade, the annual local production has not met the local demand. In pursuit of the national objectives of economic diversification; the Botswana government has initiatives and programs to assist the vegetable farmers in terms of production and marketing of their produce (Seleka, 2007; Chatterji et al., 2015).

Currently there has been availability of loans from the Citizen Entrepreneurial Development Agency (CEDA) and in the past the introduction of farm level financial incentive schemes such as Financial Assistance Policy (FAP) support for improvement of horticultural production (Rebaagetse 1999; Madisa and Assefa, 2011) and subsidy provision of farm input though the Horticulture Support programme (HSP) under Integrated Support Programme for Arable Agriculture Development (ISPAAD) (MoA, 2008). The vegetable industry is playing an important role in the socio-economic development of Botswana through reduction of unemployment as an estimated 3,852 people are employed in the sector annually (2015-2016 MoA horticulture reports) and some farmers make a living from horticultural crops which are sold in the urban markets (Seleka, 2007). According to the World Bank, (2008), 70% of the world's poor rely on agriculture as their main source of income and employment. Vegetables also provide for most households, a food source, hence seen as important balancing agents in the diets of both the poor and the wealthy, supplying proteins, a range of vitamins and minerals, energy and fibre which are needed by a human being (Eastop,1994). A wide variety of vegetables are grown in Botswana and these include among others cabbage (*Brassica capitata L.)*, rape (*Brassica napus L.*), kale (*Brassica oleracea var. acephala* L.), broccoli (*Brassica oleracea* L. *var. italic* Plenck), Swiss chard (*Beta vulgaris var. cicla* L.), garlic (*Allium sativum* L.), cauliflower (*Brassica oleracea* L.

var. botrytis L.) and many other which are not included in the list (Munthali et al., 2004; Bok et al., 2006; Obopile et al., 2008).

1.1.2. Importance of rape

Rape (*Brassica napus* L.) is a popular leafy vegetable grown for home consumption and for sale in Botswana (Bok et al., 2006; Obopile *et al.*, 2008; Madisa et al., 2010a, b) and other African countries (Swaider et al., 1992). It significantly contributes to the livelihood of both smallholder and commercial farmers (Muzemu et al., 2011). Rape leaves are rich in vitamin A, ascorbic acid and thiamine and have high levels of glucosinates, which during preparation form compounds with antioxidants and have anti-cancer activities (Holland et al., 1991).

It is grown in backyards, schools and commercial farms under irrigation. It is estimated that as much as 45% of the world's crop, including vegetables is destroyed by pests and diseases (Bhanti and Taneja, 2007). Similarly, vegetable production, rape inclusive, in Botswana is hampered by production constraints which are both biotic and abiotic factors. These include low rainfall, poor infrastructure, lack of skilled labour, shortage of funds, pests and diseases (Tiroesele and Matshela., 2015). Vegetable production in Botswana and other tropical countries is hampered mostly by the prevalence of destructive pests which contributes to a third of the losses of potential crop production (Tiroesele et al., 2015). Therefore, without sound pest control methods the annual loss may be higher (Held et al., 2003).

1.1.3. Insect pests of rape

Rape is vulnerable to attack by several insect pests including bagrada bug (*Bagrada hilaris* L.), diamond back moth (*Plutella xylostella* L.), cutworms (*Agrotis* spp), and aphids (*Brevicoryne brassicae* L.) (Bok et al., 2006). These pests can cause both direct and indirect damages to the crop resulting in yield losses. The cabbage aphid (*Brevicoryne brassicae L.* (Homoptera: Aphididae) is the most common species that attacks rape in Botswana (Bok et al., 2006; Munthali and Tshegofatso 2014). Cabbage aphid can cause significant crop loss on brassica leafy vegetables (Hamid and Ahmad, 1980; Rustamani et al., 1998; Kelly and McCullum, 1992). In Pakistan (Singh et al., 1987) observed that the economic impact of the aphid damage can be from 80% yield losses to complete crop failure, if attack comes at seedling stage. Therefore, without sound pest control methods, the annual crop losses may be higher (Held et al., 2003). Vegetables are high-value crops and the use of synthetic insecticides is intensive due to severe yield losses by insect pests under tropical conditions in Africa (Srinivasan, 2012.) and Botswana (Obopile et al., 2008, Reetsang et al., 2015).

1.1.4. Disadvantages of over-use of synthetic insecticides

Most farmers use synthetic insecticides to control aphids on crucifers (Turner and Chivinge, 1999; Sibanda et al., 2000; Obopile et al., 2008). Some of the chemicals which are commonly used to control aphids in Botswana are pyrethroids, organophosphate and carbamates (Bok et al., 2006; Obopile et al., 2008). However, there are disadvantages that come with the over-use of these chemicals. The repeated use of these chemicals may cause these aphids to develop resistance to a wide variety of insecticides. When farmers realize that pests are resistant to certain pesticides, they simply increase the dosage of pesticides, thereby increasing the residues on food crops and exerting even greater selection pressure for the increase of resistant biotypes in the population (Oruonye and Okrikata, 2010). In the end when a pesticide is no longer effective, farmers switch to different pesticides (Oruonye and Okrikata, 2010). The risks of insecticide use emanate from misuse, careless handling and inefficient application methods, resulting from large deviations from recommended doses; chemical drift to non-targets areas or run- off into the soil and leakage into ground water (Sibanda et al., 2000 and Williamson et al., 2008). In addition, most farmers especially the rural poor, who grow vegetables for home consumption cannot afford the synthetic insecticides because they are expensive or are not available in local rural shops; or because they are not familiar with the use of chemical control methods (Turner and Chivinge, 1999).

The development of resistance of aphids to many groups of synthetic pesticides that were previously used effectively against major pests and also the other disadvantages of using insecticides highlight the urgent need for effective alternative methods of controlling insect pests that are environmentally friendly, cheaper, relatively safer to humans and other non-target organisms, to ensure profitable production of important crops (Hassan et al., 1994; Ware and Whiteacre 2004; Yadav, 2005; Yanar et al., 2011). These alternative methods should also be readily accessible methods of controlling the insect pests such as cabbage aphid. The methods should be able to address many concerns raised against the use of synthetic insecticides against the pest.

1.1.5 Potential alternatives to the use of conventional synthetic insecticides

Potential alternatives to the use of conventional synthetic insecticides can include home-made organic substances, companion plants, botanically based substances (Bio-pesticides) that are known to be pesticidal and are less expensive, easy to use and less harmful to non-target organisms and the environment (Schmutterer, 1997; Munyima et al., 2004; Tao et al., 2007; Gahukar, 2007).These have been reported to have potential as components of pest management, therefore, scientific investigations are required to establish and improve their applicability and effectiveness and thus popularize their use (Stoll, 1992).

Organic pesticides or bio-pesticides represent an important option for the management of crop pests. If they can be adopted, the bio-pesticides have the potential to reduce poverty through combating yield losses from pests on crops (Kopondo, 2004; Munthali and Tshegofatso, 2014). They are pesticides derived from natural materials such as plant, animal, microbial or mineral origin (Srinivasan, 2012; US EPA). Plants and plant extracts contain a multitude of chemical substances which are insecticidal. Plant species with potential pesticidal use against pests include but not limited to the following list; garlic (*Allium sativum* L.), onion (*Allium cepa* L.), peppermint (*Mentha canadensis* L.), neem (*Azadiracta indica* A. Juss., *Melia Azadirachta* L. , *Melia Azadirachta* L. *Melia indica* A. Juss.) tobacco (*Nicotiana tabacum* L.), basil (*Ocimum basilicum* L.), tomato (*Lycopersicon esculentum* L.) blackjack (*Bidens pilosa* L.), pyrethrum (*Chrysanthemum cinerariaefolium* L.),chili pepper (*Capsicum frutescens* L.), ginger (*Zingiber officinale* L.), custard apple (*Annona resticulata* L.) sweetsop (*Annona squamosa* L.), derris spp, sabadilla (*Schoenocaulon officinale* L.), marigold (*Tagetes* spp L.) (Stoll, 1992; Weaver et al., 1994; Ware, 1996; Oruonye and Okrikata, 2010). The most used bio-pesticides are living organisms (bacteria, viruses and fungi) which are pathogenic to some insect pests (Stoll, 1992).

The other safer method that needs to be explored as alternative to the use of synthetic chemicals is companion planting by using plants to manage vegetable pests. Companion planting is a form of organic agriculture which entails the use of carbon compounds/ volatiles in crop production to control insect pests with minimal or no environmental risks (Williams et al., 1991). Vegetable plants such as garlic (*Allium sativum* L.), basil (*Ocimum basilicum* L.) and marigold (*Tagetes patula* L.) have been used as companion plants to protect other vegetables from insect attack with less costs and potential health risks of synthetic pesticides (Kim et al., 2012).

1.2 Justification

This study was intended to measure the effectiveness of botanical extracts, soap solutions and companion plants for the control of cabbage aphid on rape. Public concern about the increase usage of pesticides in vegetable production has led to consumer interest in organic vegetables.

The prevalence of destructive pests contributes about a third of the losses of potential crop production in the world (Bhanti and Taneja, 2007). Therefore, without sound pest control methods, the annual losses may be higher. Several effective control methods can be recommended for use against these insect pests. However, there is too much reliance on the use of pesticides. The use of synthetic insecticides has resulted in polluted environment, toxicity to non-target organisms, pest resistance and pesticide residues, destruction of food chains, water pollution and compromise human safety (Song et al., 2012). Their use often causes negative effects in agro-ecosystems, which include increased pest species abundance, decreased natural enemy abundance, and habitat degradation (Song et al., 2012). Other potential insecticidal problems involve farmer's exposure to insecticides during preparation and application. Thus, to counter these insecticides negative effects, there is a need to use some environmentally friendly methods which can reduce insect pest abundance such as companion planting (association resistance), botanical extracts, soap solutions and decrease emphasis on insecticide applications (Hassan et al., 1994; Ware and Whiteacre 2004; Yadav 2005 et al; Yanar et al., 2011).

The use of botanical plants as extracts and also as companion plants has the potential to reduce pest infestation as they are known to possess essential oils which are considered as insect-control agents because their bioactive chemicals are selective and have little or no harmful effect on the environment and non-target organisms (Schmutterer 1997; Munyima et al., 2004; Tao et al., 2007; Gahukar, 2007). Companion planting is an intercropping practice where two or more plants are grown together usually as a pest management method in crop production (Sedlacek et al., 2012; Tiroesele and Matshela 2015). The current study investigated the potential of our crops as components of a pest management strategy suitable for the smallholder farm producers who cannot afford expensive and dangerous synthetic insecticides.

1.3 Objectives:

The objectives of the study were to determine:

1. The effect of spraying botanical extracts and soap solutions on mortality of cabbage aphid (*Brevicoryne brassicae* L.) on rape plants under net shade conditions

2. The effect of companion planting rape with garlic (*Allium sativum L.*), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes patula* L.), and basil (*Ocimum basilicum L.*) and imidacloprid application on cabbage aphid (*Brevicoryne brassicae L.*) populations and yield of rape.

1.4 Hypotheses:

Hypothesis 1

1. Ho: Spraying botanical extracts and soap solutions has no significant effect on mortality of cabbage aphid on rape.

2. Ha: Spraying botanical extracts and soap solutions significantly increase mortality of cabbage aphid on rape.

Hypothesis 2

1. Ho: Companion planting rape with garlic (*Allium sativum* L.), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes patula* L.), and basil (*Ocimum basilicum L.*) and imidacloprid application have no effect on cabbage aphid populations and yield of rape.

2. Ha: Companion planting rape with garlic (*Allium sativum* L.), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes patula* L.), and basil (*Ocimum basilicum L.*) and imidacloprid application significantly lower cabbage aphid populations and increase yield of rape.

CHAPTER 2.0 LITERATURE REVIEW

2.1. Rape (*Brassica napus* L.)

Rape belongs to the family Brassicaceae also known as mastered/cruciferous family. There are three varieties of rape cultivated in Botswana, namely, dwarf Essex, giant Essex and giant English. In Botswana, rape may be sown all year round depending on the weather conditions prevailing in the different districts. Rape can be sown directly into the soil or transplanted. Seedlings are ready for transplanting at 4 to 5 weeks after sowing. Rape grows well on a wide range of soils at the pH of 5.5 to 7.0. However organic matter should be added when it is grown on sandy soils. The amount of fertilizer required for good growth depends on the fertility status of the soil (Bok et al., 2006). Rape prefers cool weather conditions at temperatures of 15°C and it can withstand high summer temperatures of 35°C if water supply is adequate. Day/night temperatures of 20/15°C favors prolonged leaf production until pod formation (Angadi et al., 2000).

2.1.1. Cabbage aphid (*Brevicoryne brassicae* L.)

Cabbage aphid (*'Ngadule'* in Setswana) belongs to the genus *Brevicoryne*. The name is derived from the Latin words "brevi and coryne" which refers to "small pipes". Cabbage aphid is differentiated from other aphids by its short cornicles and the greyish-green waxy coating of the body. It is 2.0 to 2.5 mm long (Bok et al., 2006; Carter and Sorensen, 2013).

2.1.2. Life cycle

The aphids reproduce in two ways that is sexual and asexual reproduction, in warm climate cabbage aphid reproduce viviparous female nymphs (Kessing and Mau 1991) and in autumn as temperatures begin to drop it reproduce oviparously (lay eggs) (Blackman and Eastop, 1984). The cabbage aphid has three life stages: egg, four nymphal instars and adult. Mature cabbage aphid can give birth to 2 to 5 live young one per day which matures in 5 to 7 days after birth (Myburgh, 1993). It can produce off springs for up to 30 days (Bok et al., 2006; Munthali and Tshegofatso, 2014). The species breeds throughout the year. According to Munthali and Tshegofatso (2014) the life cycle of the cabbage aphid is completed within 8 – 10 days and as many as 20 generations can be completed in a year (Bok et al., 2006; Munthali and Tshegofatso, 2014). The life cycle is shorter at high temperatures and longer at low temperatures however, an aphid can live up to 40 days (Kessing and Mau, 1991). Wellings and Dixon, (1987), reported that conducive conditions for aphid incidence are average temperature of 18.06°C (maximum of 22.8°C and minimum of 13.31°C) under the influence of high relative humidity, with a range of 80.7% to 86.5%.

2.1.3. Damage caused by cabbage aphid

Rourke et al., (2003) reported that economic damage caused by the cabbage aphid is sporadic and most severe in hot, dry weather. Cabbage aphid occurs in large numbers on leaves and growing points of infested leafy vegetables and cause direct and indirect damage to the plant (Stoll, 1992; Munthali and Tshegofatso, 2014). Cabbage aphids prefer feeding on young leaves. Colonies of aphids are found on the upper and lower leaf surfaces, in leaf folds, along the leafstalk and near the leaf axils (Habimana and Hakizayezu, 2014). They tend to feed on the undersides by piercing and sucking of sap from the attacked parts; probably from the cell's protoplasts and vacuoles (Powell, 1991; Martin et al., 1997). This results in stunted growth and deformation of the plant (McKinley, 1992 Munthali et al., 2004; Munthali 2009). Continued feeding causes wilting and yellowing of the leaves (Hill, 1983; Munthali and Tshegofatso, 2014). Affected leaves wrap or curl inwards (Dube et al., 1999). Infestation reduces the quality of the produce through presence of the insects and contamination of the leaves with wax, honeydew and black sooty mould that grows on the leaves (McKinley, 1992).

The cabbage aphid is a vector of many important virus diseases of cruciferous plants (Kessing and Mau, 1991). It transmits diseases like; *Turnip mosaic virus*, the *Cauliflower mosaic virus* (Stoll 1992; Chivasa, 2002) and the *Potato leaf roll virus* (Nault, 1997) from plant to plant on cruciferous vegetables. The virus causes; mottling, yellowing, curling of leaves and stunting of the plant. Losses can be great, and difficult to prevent through the control of aphids because infection occurs even when aphid numbers are very low; it only takes a few minutes for the aphid to transmit the virus while it takes a much longer time to kill the aphid with an insecticide (Kessing and Mau, 1991).

2.1.4. Economic Importance of cabbage aphid on production of rape and other brassicas

Cabbage aphid when not controlled may cause total crop losses on brassica leafy vegetables in the world especially if plants are attacked at the seedling stage (Munthali et al., 2004; Obopile et al., 2008; Munthali, 2009; Khan et al., 2015; Muhammad et al., 2011). It is important to have a comprehensive understanding of this pest and its associated control measures so that its spread and damage can be prevented.

Pest damage is a threat to a farmer as it causes economic losses through lost output, income and investment. The economic impacts of pests are complex and can have immediate effects on crop producers (Song et al., 2010). The economic impact emanating from pests is the yield losses which have a negative impact on farm income and threatens food security in the country. Furthermore, farmers get discouraged or lose hope in agriculture, especially vegetable production. However, this results in our country importing vegetables from neighboring countries. The summary of horticulture produces imports as of April 2009 amount to 4652.04 tons which amount to a total of P20 153 368.34, imported rape amount to 4.17 tons which amount to P89892.00 (Statistics Botswana, 2015). Early detection of aphids is important as they can multiply rapidly.

2.1.5. Ecology of cabbage aphid

According to Blackman and Eastop, (2000), female aphids may lay eggs or give birth to wingless offspring, known as nymphs. In warm parts of the world, no male aphids are produced while female do not lay eggs but give birth to small nymphs (Blackman and Eastop, 2000). Aphids live in clusters or colonies, they are found on the upper and lower leaf surfaces (Habimana and Hakizayezu, 2014). As the colony grows winged aphids are produced which fly away looking for new plants to start a new colony; winged aphids are produced when they need to migrate under overcrowded conditions with limited food source and when conditions are not favorable (Blackman and Eastop, 2000). Furthermore, Blackman and Eastop, (2000) indicated that warm and dry weather is particularly favorable for rapid increase of aphid numbers. Aphids feed by sucking sap from their host plants (Munthali, 2009; Munthali and Tshegofatso, 2014; Habimana and Hakizayezu, 2014; Tiroesele and Matshela, 2015). Habimana and Hakizayezu, (2014) reported that aphids produce a sugary waste product called honeydew, which is fed on by ants, ants in turn protect aphids from natural enemies.

2.2. Management/ control of cabbage aphid

2.2.1. Overview

Aphids can be managed effectively through a combination of control measures that ensure good management of the growing environment. There are several effective control methods that can be used against vegetable insect pests. This includes a combination of use of resistant varieties, cultural, biological and chemical control strategies which can help reduce aphid infestation while maintaining high quantity and quality of produce. Resistance to cabbage aphid has been demonstrated in some rape cultivars in India, Europe and Botswana (Munthali, 2009; Munthali and Tshegofatso, 2014) and in some species and cultivars of brassicas (Singh and Ellis, 1993; Ellis et al., 1998). Finch and Collier, (2000) showed that partial host plant resistance allows a lower dose of insecticides to be effective when aphid populations exceed a threshold. In brassicas, the mechanisms that have been attributed to resistance against the cabbage aphid are antibiosis which is the adverse effect of host plant on development and reproduction of insect pests feeding on resistant plants; and antixenosis which is a characteristic which adversely affects the normal behaviour of an insect pest (Kalule and Wright, 2002; Munthali, 2009). The potential use of resistant brassica leafy vegetables to control cabbage pests has not been investigated in Botswana. However, there are several brassica leafy vegetables recommended for the use in Botswana (Bok et al., 2006; Munthali et al., 2004), though their relative resistance to cabbage aphid has not been determined.

2.2.2. Cultural control

According to Kumar, (2003), cultural control method of pests involves creating environment which is unfavorable for multiplication of pests and thereby averting the damage and limits its severity. Cultural practices should be included in any pest integrated control program, because when used alone it cannot give satisfactory results. Examples of cultural practices which limit the need for chemical use include:

a. field sanitation- ploughing of fields immediately after harvest have been found to prevent the spread of aphids to other crops (Griffin and Williamson, 2012), b. burying crop residues actually destroys the overwintering habitat of the pests such as aphids (Hines and Hutchison, 2013), c. destruction of alternate host plants like mustards or other cruciferous weeds from the fields and surrounding areas removes sources of aphid infestation on the crop (Finch and Collier, 2007; Natwicket, 2009) and. Planting nectar yielding plants within the vicinity of the crop to attract beneficial insects such as psyrphid flies which are important predators of the cabbage aphid (Webb, 2010) and e. Crop rotation of crucifers with non-host crops (Kessing and Mau, 1991). According to Song, et al., (2012) crop rotation system offers numerous advantages in the soil structure, fertility and erosion management as well as aiding in control of various pest species. Crop rotation for pest management involves alternating susceptible and insusceptible crops in a rotation cycle. Crop rotation is limited to control of highly mobile insects (Song et al., 2012).

2.2.3. Biological control

Kumar, (2003) states that biological control is a method of controlling pests to reduce their populations in the fields using other living organisms that is; parasitoids, predators and pathogens. This method involves the manipulation of natural enemies of pests to reduce their population to a level where economic losses due to them are tolerable. Biological control method restores a natural balance between pest and predator and keeps pests down to an acceptable level. Its agents can be used to control pests, but they do not eliminate the target pests, instead they can only restrict their abundance to a level below the economic threshold. According to Williams et al., (1991) ladybugs are voracious predators of aphids. Ladybird beetles are generally considered to be useful insects as many species feed on soft bodied insects like aphids, jassids, psyllids whiteflies, scale insects, small larvae and phytophagus mites which are injurious to agricultural crops (Rafi et al., 2005).

Biological control can potentially have positive and negative effects on biodiversity. Protecting habitats that foster the population and survival of natural enemies cut down the workload and reduce the need for the use of pesticides (Natwicket, 2009). The most common problems with biological control occur via predation or other attacks on non-target species (Eastop, 1994). Often a biological control agent is imported into an area to reduce the competitive advantage of an exotic species that has previously invaded or been introduced there, the aim being to thereby protect the existing native species (Collier and Finch, 2007). However, the introduced control agents do not always target only the intended species. To develop or find a biological control that exerts control only on the targeted species is a very lengthy process of research and experiments.

2.2.4. Chemical control

The alternative to natural pest control is using chemical pesticides which interfere with the biological processes of many living organisms. Insecticides can be applied as seed treatment, as granules at time of planting and as foliar sprays. However, insecticides do not solve the problem instead its use has increased tenfold while crop losses from pest damage have doubled (Ware, 1980). Many insecticides are effective against aphids. According to Kessing and Mau, (1991), maximum control with minimum efforts can be achieved by using the proper chemical mix with well-adjusted spray equipment. Commercial growers use synthetic pesticides like; Malathion and dimethoate (Rourke et al., 2003) to control aphids. Obopile et al., (2008) found that cypermethrin is one of the most widely used insecticides in Botswana.

Even though cypermethrin is widely used in Botswana (Obopile et al., 2008), its broad-spectrum characteristic causes mortality of non-target beneficial insects in the field and reduce invertebrate biodiversity (Legwaila et al., 2014). This loss of biodiversity is undesirable, especially because it can lead to insecticide-induced pest resurgence (Hardin et al., 1995).

Time of application of aphicides is very important to keep aphids under control while conserving populations of natural enemies (Griffin and Williamson, 2012). (Ahmad and Akhtar, 2013) reported that in Pakistan aphids developed resistance to chemicals including methomly, emamectin benzoate and pyretroids such as (cypermethrin, lambcyhalothrin, bifenthrin and deltamethrin) and neonicotinoids such as (imidacloprid, acetamiprid and thiamethoxam). Their resistance level was found to increase progressively in concurrence with regular use on vegetables. A study in USA on reduced rates of pymetrozine and natural enemies in control of cabbage aphid reports that 98%reduction level was obtained when low dose of pymetrozine was combined with different biological agents (lady beetle and parasitoid) (Acheampong and Stark, 2004). Bode, (1981) reported that a satisfactory control of aphids was achieved by using reduced dosage rates of the selective pesticide, pirimicarb and biological agents. Very efficient control of the cereal aphid (*Shizaphis graminum* Rond.) in sorghum was achieved with reduced dosage rates of two broad-spectrum pesticides, carbofuran and chlopyrifos (Smith et al., 1993).

2.2.5. Botanical insecticides for the management of cabbage aphids

Botanical insecticides are naturally occurring chemicals (insect toxins) extracted or derived from plants or minerals. The practice of using plant derivatives or botanical insecticides in agriculture dates back thousands of years ago in ancient China, Egypt, Greece and India (Thacker, 2002). In Europe and North America, the documented use of botanicals extends back more than 150 years; predating discoveries of the major classes of synthetic chemical insecticides (organochlorines, organophosphates, carbamates, pyrethroids and nicotinoids) which occurred between the mid-1930s and the 1950s (Isman, 2006). Unfortunately, the discovery of synthetic insecticides in recent history displaced the use of botanical pesticides from the important role they used to play in agriculture to a minor role (Isman, 2006).

The greatest benefits of use of botanical insecticides can best be realized in developing countries where the majority of farmers are not able to afford synthetic insecticides and where the traditional use of plants and plant derivatives for protection of stored products was long established (Isman, 2005). Preparation of pesticidal plant extracts is relatively cost effective and more suitable for use where the farming community requires a relatively easy method of preparing spray solutions for application compared to formulations used in application of synthetic pesticides (Gahukar, 2007).

In industrialized countries, botanical insecticides are thought to be best suited for use in organic food production, but they can also play a much greater role in the post-harvest protection of food products (Yusuf et al, 1998; Anaso, 1999; Lale and Yusuf, 2001; Isman 2005). Growers must gain confidence in botanical insecticides that do not produce an immediate knockdown effect and do not have long residual action (Isman, 1997, 2006).

2.2.5.1 Mode of action of botanical insecticides on insect pests

Botanical insecticides have been reported to have insecticidal and repellent effects against insect pests. Some have also been found to have antifeedant, growth regulatory, oviposition inhibitory, sterility inducing, antifungal, acaricidal and nematicidal properties (Murthy et al., 1981, Pandey, et al., 1987; Messina and Renwick, 1983; Stoll 1992; Isman, 1998, 2000; Anaso, 1999; Thacker, 2002; Buckle, 2003; Yanikoglu 2006; Koul et al., 2008; Abdul-azeez 2009; Khater, 2012). Yusuf et al., (1998) observed that the powder of *Zingiber officinale* L., *Eucalyptus camaldulensis* L., *Ocimum basilicum* L., *Capsicum frutescens* L. and wood ash of *Khaya senegalensis* L. are effective in the control of maize weevil (*Sitophilus zeamais*) in stored maize, thus all the plant materials were found to significantly affect the survival of the *S. zeamais* at different concentration rates. Abdul-azeez, (2009), applied cashew nut shell extract on cowpea pods infested with aphids and found that the treatment had insecticidal effects on aphids. Also, the potential for use of plant extracts from these species in integrated pest management strategies against major pests has been recognized (Charleston et al., 2005). Unlike synthetic pesticides, insects do not develop resistance to botanical pesticides as fast as conventional synthetic pesticides may be due to a wide range of insecticidal effectiveness they possess. The resistancy to insects also remains one of the major difficulties that stand in the way of exploitation of pesticidal plants.

2.2.5.2 Potential use of garlic extracts in pest management

Simmonds (1992) reported that *Allium* spp. are very effective anti-feedants and have strong pungent repelling action, they can be planted as a companion crop with other vegetables and used as an insect repellent. (Pahla et al., 2014) found that intercropping rape with garlic is effective in controlling aphids and improves rape yield. When intercropped with cabbage, garlic deters diamond back moth from cabbage and when inter cropped with sorghum, it repels the sorghum shoot fly from infesting the sorghum shoot. Garlic can be planted around fruit trees to repel aphids, fruit tree borer, termites, mice and other pests (West, 2002). It is known to affect different developmental stages of insects (egg, larvae and adults). The active ingredient is diallyl disulphate which is largely responsible for the garlic odor (Simmonds, 1992). Garlic is reported to be effective against the many major pests of important crops. It can be crushed dried or fresh and the extract material can be mixed with water and then applied onto infested plants as spray. Before use the solution is diluted with water, but the amount of water used depends on the strength of the garlic. However, the effective dosages against each target species have not been properly determined (Stoll, 1992).

Mhazo et al., (2011) found that garlic was an effective organic pesticide against aphids on rape and that addition of paraffin to the garlic spray improved its effectiveness against aphids, though the reason for using paraffin is not clear. Mhazo et al., (2011) used garlic and lippia as simple extracts mixture in a field trail at the Horticulture Research Centre in Marondera, Zimbabwe and they were also mixed with other botanical materials such as chilies, liquid dish soap and paraffin separately. Fresh botanical materials were crushed, and their mixtures were soaked in water for 24 hours, then the mixtures were strained and stored in a glass jar and kept in the fridge, they indicated that the mixture can last for a week before use. However, the different botanical pesticides were sprayed on rape plants without dilution after preparation. The data was collected on aphid mortality per plant based on the score before spraying out 1, 4, 8 and 12 days after spraying. According to their results solanum and garlic were effective against aphids on rape plants. Furthermore, they recommended that more research must be done to test other unknown plants with pesticidal effects and to identify new plants with pesticidal properties in different areas. Garlic is also known to be effective against several species of aphids, the army worm (*Spodoptera litura* L.), the false codling moth (*Cryptophlebia leucotreta* L.), the Colorado beetle (*Leptinotarsa decemlineata L.*), the imported cabbage worm (*Pieris rapae* L.) and several species of wire worms (Stoll, 1992; Mhazo et al., 2011). Garlic that will be used as an insecticide should not be grown with mineral fertilizers since it has been established that heavy doses of mineral fertilizers reduce the concentration of the effective substances in garlic.

In a nursery tunnel research conducted by Sohail et al., (2012), dried garlic and other botanicals were grinded in a grinding machine and soaked for 24 hours, then filtered using a muslin cloth and sprayed at the rate of 50ml of solution in 2.5 litres of water on the cutting of the tea tree to control aphids. Botanical pesticides were used to compare their effectiveness in relation to control the pest at the rate of 2 % of the extracts. The results indicated that there were significant variations in insect mortality in different botanical pesticides observed at 24 hours, 72 hours, one week and two weeks of spray. From their study they concluded that application of both the plant extracts used reduced the aphid populations. The botanical pesticides showed high efficacy against aphid. They further said that natural pesticides have potential for use in agriculture sector of plant protection, the cost benefit ratios of the botanical pesticides used proved economical for the end users and would be applicable with any extra burden on the farmers, whereas the pesticide used were easily affordable for the lo-income farmers.

2.2.5.3 Potential use of marigold extracts in pest management

The extracts of members of the Marigolds (*Tagetes* spp.) are insecticidal against many pests. Weaver et al., (1994 and 1997) reported that all tissues of *T. munita* tissues tested contained insecticidal components that are effective against pest species of stored products. The plant acts as a repellent, anti-feedant and has fumigant effects on target pests. Marigold extracts contains α-terthienyl and bithienyl as the active insecticidal components involved in protection against pests (Morallo-Rejesus and Decena, 1982). However, the highest concentration of the active ingredient is in the leaves and floral parts of the marigold (Weaver et al., 1994). Both the floral and foliar extracts contain compounds that are volatile with a rapid fumigant mode of action (Weaver et al., 1994). The plant extract is effective against aphid such as the mustard aphid (*Lipaphis erysimi* L.) (Ali et al., 2010), cabbage aphid (Phoofolo et al., 2013) and red spider mites (*Tetranychus* spp.) on vegetables. The powder of marigold extracts is reported to be effective against maize and Mexican bean weevils (*Sitophilus zeamais* L.) (Weaver et al., 1994, 1997; Keita et al., 2000). Another mode of action of *T. minuta* is repellency.

Marigold can be used in mixed or intercropping systems to reduce pests on companion crops. This potential has been demonstrated in intercrops with cabbage. The cabbage intercropped with marigold suffered significantly less cabbage aphid infestation when compared with a mono-cropped cabbage (Jankowska et al., 2009). Phoofolo et al., (2013), used powdered marigold extracts mixed with different extracts, aceton 99.5%, methanol 99.5%, distilled water and the mixture of acetone/menthanol/water (7:7:1, v; v) in a laboratory experiment whereby a leave dip method was used; wingless adult's aphids from the greenhouse were placed in the metal mesh container and were dipped for 10 seconds in the control and different plant extract solutions. Aphids were then transferred to a fresh-cut cabbage leaf square (2 x 2 cm) on the moist filter paper in a petri dish (90 mm diameter, 15 mm depth). The petri-dish was then placed in the growth chamber for 48hours at 22°C. After 48 hours' aphids were classified as dead or alive and then counted. In conclusion they said that the botanical extracts of marigold obtained using water as a solvent is as effective as botanical extracts from organic solvents system in killing cabbage aphids. They also found that the aqueous extracts of marigold also reduced fecundity on cabbage aphids with the magnitude comparable to those obtained from organic solvents. Their results also augured well for the practical use of marigold as a source of effective easily available botanical pesticides to resource poor farmers in production of cabbage. However, they planned to study insecticidal effects of the whole plants of marigold grown in an intercropping system with vegetables. Their results were consistent with the findings of Tomova et al., (2005) who showed that fractionated tagetes oil volatiles reduced fecundities of three species of aphids (*Acyrthosiphonpisum* (Harris), *Myzus persicae* (Sulzer) and *Aulacorthum solani* (Kaltenbach)).

2.3 Use of soap solutions in the management of cabbage aphids

Soap is a substance used for washing and cleaning, made of a compound of natural oils or fats with sodium hydroxide or another alkali and typically having perfume and colouring added. Records of the use of soap sprays to control pests date back to the late 1800s and continue into the 1900s (Pedigo, 2002). Although spraying with soap to control major pests declined with the advent of new synthetic insecticides in the mid1940s, there has been a renewed interest in the potential use of soaps as pesticides with the recent growing desire for alternatives to synthetic insecticides (Pedigo, 2002; Pedigo 2006). Soap solutions have been used to control insects for more than 200 years (Cranshaw, 2008). Soap solution is one of the botanically based substances which have insecticidal and acaricidal properties against major pests (Cranshaw, 2008).

Soap solutions act as contact insecticide which are particularly effective against soft bodied insects like aphids that have a waxy covering (Nayar et al., 1990). The active ingredients in insecticidal soaps are fatty acids, which affect the insect's nervous system and remove protective waxes on the surface of the insect cuticle (Pedigo, 2002; Chapman, 1997). Isman, (2006) reported that soap solutions also kill small insects and mites through suffocation by blocking the spiracles. Insecticidal soaps are selective insecticides with minimum adverse effects on beneficial organisms such as lady bird beetles, green lacewings, honeybees and many other insect species (Cranshaw, 2008). Commercial soap products, such as M – Pede soap, dish washing liquids comprise of potassium salts (particularly potassium oleate) which are pesticidal against aphids, spider mites, mealy bugs and whiteflies (Pedigo, 2002; Isman, 2006). Soap sprays are only effective when the liquid encounters the insect and they have little or no residual effect. Therefore, repeated applications at short time intervals are necessary to achieve the desired levels of pest suppression. Flint (1999) found that soaps only killed aphids that were present on the day the solutions were sprayed but were not effective on subsequent days and so concluded that applications need to be repeated for sustained effectiveness over a longer period. However, Mhazo et al. (2011), found that soap can be added to organic pesticides to improve efficacy of the chemicals because it acts as a surfactant (surfactants are used for improving the performance of the organic pesticides or they are used to facilitate and accentuate the emulsifying, dispersing, spreading, wetting or other surface modifying properties of liquids) without which the spray will drain off from the leaf surface.

Barry (1996) showed that insecticidal soaps can be specifically formulated to be non-phytotoxic, effective and efficient agents for killing and controlling aphids and other pests, particularly when used under home environments and in small greenhouses. Randon et al. (2006) also found that insecticidal soaps are relatively safe, with low toxicity to humans and pets; easy to apply and generally lacked the noxious fumes of conventional synthetic insecticides. However, one of the serious potential drawbacks to the use of soap-detergent sprays is their potential to cause plant injury. Randon et al. (2006) and Cranshaw (2008) found that soap sprays burnt leaves of sensitive plants; therefore, they have to be washed off the plant few hours after application. Because of this they recommended that soap-detergent sprays should be tested for phytotoxicity problems on a small area one or two days before an extensive area is treated.

2.4 Companion planting in the management of cabbage aphids

Companion planting method is the arrangement of different plants according to their potential to benefit each other (Sedlacek et al., 2012). These plants are alternated in a single row and have natural properties that help them grow and deter pests when planted close by as they act as a trap for harmful insects and attract beneficial insects that eat pests. Making use of these natural properties is a way to fit more plants into a smaller space, reduce pest problems hence increasing vegetable yields. Companions must be planted very near each other in order to have any effect on each other and this is well-adapted to small gardens where plants are grown in proximity and space is at a premium (Bakr et al., 2010).

Plants respond to insect feeding damage by releasing a variety of volatiles from the damaged site, and the profile of the volatiles emitted is markedly different from those of undamaged or mechanically damaged plants (Held et al., 2003). An undamaged plant maintains a baseline level of volatile metabolites that are released from the surface of the leaf and/or from accumulated storage sites in the leaf. Companion plants such as *Allium* spp, basil and *Tagetes* spp, produce volatile oils and other constituents which are known to have fumigant, repellent and population suppressant effects towards insect pests. These plants are a special type of plant group as they have both medicinal and aromatic properties (Song et al., 2010). The number of volatiles released by individual plants can vary depending on the management practices and environmental conditions that influence the plant's physiology. Companion planting can potentially lower input costs and decrease reliance on insecticides (Seagraves et al., 2006), but it must be accompanied by other good gardening practices, such as timely watering and careful spacing of appropriate plants (Bakr et al., 2010).

2.4.1 Mode of action of companion planting against insect pests

The success of companion planting as a tool for insect pest control has been variously attributed to interference with host location by physical obstruction, visual camouflage, masking; repellent volatiles; and increased populations of natural enemies (Finch and Collier, 2007). It also involves the interaction between neighboring plant species which leads to the reduction in herbivory on one or more of the associated plants. It has been observed that the herbivores often are less likely to remain in host patches when hosts are inter-planted with companions. There is a hypothesis that volatiles produced by non-host plants which are inter-planted with the host plants, may repel or mask those produced by hosts (Kim et al., 2012). The companion plants are capable of releasing volatiles which repel the insects, attract both parasitic and predatory insects that are natural enemies of the herbivores. They may also induce defense responses in neighboring plants.

2.4.2 Garlic and its potential effectiveness as a companion plant

Garlic releases different proportions of constituents of volatile blends. Leaves normally release small quantities of volatile chemicals than the bulb, but when the plant leaves are damaged by herbivorous insects, many more volatiles are released (Huang et al., *2000*). These volatiles released by garlic can help control pests by repelling them. It also deters beetles, snails and moths. Their fragrances can distract pests away or mask the odor from the pests' normal favorite plants and this help confuse hungry pests that might go after the crops. The mix alone tends to repel many flying insect pests like aphids, which get confused by the smell of this companion and give up if they do not find what they are looking for soon enough (Zhao et al., 2013). Intercropping with garlic reduces the abundance of herbivores and species richness or induces migration outside, especially in highly mobile herbivores or those sensitive to the odors, which may interfere with feeding, breeding and host location activities (Huang et al., 2000).

Held et al. (2003), tested repellence of volatiles from some aromatic non-hosts: red cedar shavings *(Juniperus virginiana L.)*, fruits from gingko (*Gingko biloba L.*) and confirmed that Cedar wood or cedar oil vapors are repellent or toxic to certain household pests. According to Pahla et al. (2014), garlic was the most effective intercrop as evidenced by lowest aphid, lowest leaf damage and highest rape fresh leaf mass. The effectiveness of garlic in reducing aphid population can be attributed to the fact that the plant contains a group of closely related compound (allicins) which are responsible for the pesticidal properties (Mudzingwa et al., 2013) and repellence against aphids (Tada et al., 1988).

2.4.3 Marigold and its potential effectiveness as a companion plant

Marigold (*Tagete spatula L.*) is an annual herb which produces volatiles that attract both parasitic and predatory insects that are natural enemies of the herbivores such as parasitic wasps, ladybugs and lacewings and it is one of the companions which can effectively control pests by providing habitat for beneficial parasitic and predatory insects (Song et al., 2012). Marigold does not only provide alternate habitation but also provides alternate food or intermediate hosts for predators. It provides more nectar and pollen during its flowering stage for predator natural enemies, which may lead to the attraction of more predator species, thus leading to an overall increase in predator numbers thus natural enemies in an intercropped system (Seagraves et al., 2006).

According to Held et al. (2003), intercropping white cabbage with French marigold and Pot Marigold (*Calendula officinalis L.)* significantly reduced cabbage aphid, flea beetles (*Phyllotreta*) and diamondback moth population densities by producing volatiles which attract natural enemies such as parasitic wasps and ladybugs. Marigold can also be used as a trap crop whereby it can harbor harmful insects. This technique works best when the trap crop completely surrounds the garden area, so that approaching insects will encounter the trap crop first, no matter what direction they approach from, so that they can stay away from the crop the farmer really cares about (Seagraves et al., 2006). Held et al. (2003), found that intercropping with French marigold significantly reduces cabbage aphid population densities by producing volatiles which attract natural enemies such as parasitic wasps and ladybugs. According to Tiroesele and Matshela (2015), less aphid infestations were observed in kale intercropped with marigold due to the presence of lady bird bettles which might have been attracted by marigold.

2.4.4 Basil and its potential effectiveness as a companion plant

The essential oils of basil are of complex and variable composition. Within the species, several different chemical races exist, and the climate, soil, cultivation practices and time of harvest influence not only the quantity, but also the composition of the essential oil. The most important aroma components are 1, 8 cineol, linalool, citral, methyl chavicol (estragole), eugenol and methyl cinnamate, although not necessarily in this order, in fact, hardly any basil type contains all these compounds in significant quantities. Other compounds may also be present, depending on cultivar (Kim et al., 2012). According to Szendrei et al., (2009); basil produces a strong smell which deters pests by putting them off the scent. The odor of the herb can mask an otherwise tasty plant from its insect pest.

Basil is an annual herb which has a scent that can also be used to confuse or deter insects from attacking crops like brassicas. Basil repels whiteflies, asparagus beetles, carrot flies, flies, mosquitoes, and tomato hornworm (Song et al., 2012). According to Kim et al. (2012) basil repels aphids and mosquitoes and it is said to slow the growth of milkweed bugs. They further mentioned that it can also act as a fungicide. Basil has been reported to attract butterflies, which are beneficial in pollinating plants (Zhao et al., 2013). There is limited information on how basil is used as a companion plant, but the crop can be used to control insect pests in fields. Tiroesele and Matshela (2015), reported that kale intercropped with basil had no aphid incidence at all from the first week until the end of the experiment proving it to effective in controlling aphids. They further reported that this was because basil produced the strongest aromatic smell which tends to repel aphids hence reducing the infestation levels.

2.4.5 Peppermint and its potential effectiveness as a companion plant

According to Isman (2006), Pepper mint has been used for pest control. It can be used as a companion plant with cabbage, kohlrabi, broccoli and kale and rape as it enhances their growth Parker et al. (2013). Generally, mint is an annual aromatic herb which is recommended for their supposed repellent and deterrent qualities (Anon, 2004a). The essential oils of mint are of complex and variable composition. The most abundant compounds responsible for this were: terpenes (with carvone, dihydro-carvone, D-limonene and eucalyptol or 1, 8-cineole as the most represented); alcohol (mainly 1-octen-3-ol and 3-methyl-1-butanol); ketones (e.g. 3-octanone); esters (e.g. 2-methyl-ethyl ester-butanoic acid) (Gochev, 2008). Peppermint repels ants, aphids, cabbage fly, cabbage looper and flea beetles. It is also known to attract bees and beneficial insects http://www.ourherbgarden.com/ Accessed date: 11 / 05/ 2018. Finch et al. (2003), demonstrated that commonly grown companion plants used for their repellent properties, mint did not repel the onion fly or cabbage root fly (D. *radicum*), but rather interrupted their host finding and selecting behavior. Thus, even though the companion plants did not repel pests, they were still able to disrupt host plant finding through alternative mechanism.

These four aromatic companion plants above have demonstrated that intercropping with them can significantly reduce abundances of pests and increases abundances of natural enemies. Parker et al. (2013), indicated that designing companion planting schemes pose several impeding issues. For instance, optimal distances between the companion plant and the target crop needs to be determined before specific recommendations can be made. However, there remains limited understanding of how intercropping with them regulates the ratio of natural enemies to pests and arthropod community structure.

Although botanicals extracts, soap solutions and companion plants have been recommended for use in different parts of the world, the efficacy of these botanicals, soap solutions and companion plants have not been evaluated in Botswana. Most of the experiments to evaluate these plants were carried out in laboratory settings and do not necessarily represent field conditions (Finch and Collier, 2000). Therefore, the objective of this study was to evaluate the efficacy of botanicals, soap solutions and companion plants against cabbage aphid on rape under net shade and field conditions.

CHAPTER 3.0 MATERIALS AND METHODS

3.1 The effect of spraying botanical extracts and soap solutions on mortality of cabbage aphid (*Brevicoryne brassicae* L.) on rape plants under net shade conditions

3.1.1 Experimental site

The study was carried out in a net shade at the Botswana University of Agriculture and Natural Resources from 8 January to 27 July 2018. The University is located at Sebele approximately 10 km north of Gaborone city, Botswana along the A1 road north – south highway at (Latitude 24^{0}34' 25" S, Longitude 25^{0}57' 0" E; altitude: 994 m). The climate for the study is semi – arid, with an average rainfall of 538 mm (30 year mean) with most rainfall being received between October and March/April (Statistics Botswana 2018). The soils are light sandy loams (76 % sand, 10 % silt and 14 % clay) with low water holding capacity, low cation exchange capacity and pH of 6.3 (Toteng *et al.*, 2014). The net shade frame was15m long m x 5m wide 5m high covered with 60 % black net cloth covered over top of the steel frame. The seedlings for crops which would be used as companion plants were raised under an open space at Malotwana 7 km north of Mochudi in Kgatleng district, 5 km east of A1 road at (Latitude 24.4167^0, 2425'0.120'S, Longitude 26.15^0, 26'60.000'E, altitude: 942 M). The climate of the area is semi- arid with the average annual temperature of 29 °C with the average rainfall of 583 mm and the soils are light sandy loam.

3.1.2 Experimental design and treatments

The experiment was a 2 x12 factorial completely randomized design (CRD) with four replications. Factor A was season (summer and winter), Factor B was spray treatments in percentage wet volume (w/v) as follows: T1: 20% garlic; T2:10% garlic; T3: 20% basil; T4: 10% basil; T5: 20% mint; T6: 10% mint; T7: 20% marigold; T8: 10% marigold; T9: 10% liquid soap; T10: 5% liquid soap; T11: distilled water (negative control); T12: imidacloprid (20g/L) (positive control). The application rates were informed by work from other researches, however it was opted to use the lowest and the highest application rate among as compared to other researchers. Two trials of the experiment were carried out, one in summer and the other in winter. The summer and winter trials were conducted from 8 January to 24 February and 4 June to 20 July 2018, respectively.

3.1.3 Experimental procedure

Insect-proof cages 40 cm long, 40 cm wide 40 cm high covered with 32 x 32 mesh size lumite screen (Munthali and Tshegofatso, 2014) were used (Appendix1). This was done to prevent infestation from natural population or escape of the aphids from the artificially infested plants in the cages. Every cage had a door with a sleeve which was used during the watering of plants and for artificial infestation, application of sprays and removal of plants during pest assessment. Potting plastic bags (12 cm in diameter and 15 cm deep) were filled with loam soil. Two rape seeds were sown in plastic pots filled with loam soil at a depth of 5mm and later after emergence at the three-leaf stage; plants were thinned to remain with one plant in each pot (Appendix 2). Each potted plant was labeled to indicate the treatment and the date of application and placed in a cage. The soil used in the potting plastic bags was not tested before. However, Nutrifeed fertilizer (N- 6.5, P- 2.7 %, K- 13.0 %, Ca- 7.0 %, Mg- 2.2 %, S- 7.5 %, plus; iron, manganese, boron, zinc, copper and molybdenum) was added at the rate of 5g around each plant. Plants were watered daily to prevent wilting.

3.1.4 Preparation of water-based botanical extracts

Water based botanical extracts were prepared using 10-week-old fresh botanical crops picked from the backyard plots at Malotwana and garlic cloves were bought from local shops. Plant materials were cleaned and washed thoroughly before crushing or grinding with an electrical blender. The extracts were formulated using the modified method of Stoll (1992) and Iqbal *et al.* (2004). For each fresh garlic, marigold, basil and mint 200 grams were pulverized with 50 mL Monterey horticultural mineral oil (Monterey, California, USA) (Stoll, 1992; oisat.org/control methods/...horticultural_oil.html) in a blending machine (Logic blender, model; RSH-080475. Santon, South Africa). Leaves, roots and flowers of marigold were mixed and used (Fusire, 2008), while for mint and basil only fresh leaves and for garlic gloves were used (Stoll, 1992, Iqbal et al., 2004). The infusion of the botanicals and mineral oil were each transferred into 1000mL of boiling water and allowed to soak for 24 hours separately in plastic containers covered with a lid. A kitchen plastic serving spoon was used for stirring and mixing the infusion of botanicals and mineral oil in the water thoroughly. 250μm sieve and fine cloths (Stoll, 1992) were used for sieving the solutions. Each botanical mixture was sieved with a separate cloth to avoid cross contamination. The final solutions of the botanical extracts were bottled in clear plastic bottles closed tight and kept in the fridge at ± 4°C until further use because they lose activity if left open, (http://herbsforhealth.about.com/cs/pestcontrol) and they degrade rapidly in sunlight, air and moisture (Buss and Park-Brown, 2006). The standard solutions (20% w/v) of the botanicals above were diluted to 10% by mixing 500 mL of the solution with 500 mL of distilled water.

3.1.5 Preparation of Soap solution

Liquid soap solutions of 5% and 10% (v/v) were prepared by diluting 50 and 100ml of sunlight liquid soap (Unilever South Africa (Pty) Ltd, Durban, South Africa) with 1litre of distilled water, respectively.

3.1.6 Chemical/pesticide

Efekto Aphicide-plus (Bayer CropScience, South Africa) is a systemic suspension concentrate whose active ingredient is imidacloprid (neonicotinoids). The recommended rate of 20 g/L of water was used.

3.1.7 Aphid rearing and infestation

The rape seedlings used for rearing cabbage aphid were grown in the plastic pots and placed in the cages under the net-shade. Cabbage aphid rearing was started by collecting aphids from rape in backyard gardens in Malotwana. Potted seedlings of each treatment were artificially infested with 4 mature cabbage aphids at the five-leaf stage (Appendix 3a). Aphids were placed on each plant using a fine haired camel brush and left to produce nymphs for five (5) days and then removed in order to start the experiment with nymphs of same age. For each plant 100 aphids were used at the start of the spray treatments.

3.1.8 Spraying

Spraying dilutions for botanical extracts, soap solution and aphicide were prepared at the time of spraying in the net shade. Two one litre hand trigger sprayers that produce a fine spray of a relatively narrow range droplet sizes were used to apply the spray solutions. One sprayer was used to spray botanical solutions and the other one distilled water and imidacloprid. After spraying the sprayers were triple rinsed with water and then washed with soap before they were used for spraying another solution. Full spray cover was maintained while avoiding dripping and blowing away of aphids. Each seedling was sprayed separately. Imidacloprid was sprayed on day 1 and day 8 of the 14-day experiment while the botanical solutions were sprayed every day. The spraying frequencies for Imidacloprid and botanical extracts varied because according to (Isman, 1997, 2006) the botanicals do not produce an immediate knockdown effect and do not have long residual action, therefore for their effectiveness they have to be applied on regular basis as compared to synthetic aphicides.

3.1.9 Data collection

At each sampling day numbers of live and dead aphids on each plant were recorded just before spraying. A rectangular tray made of thick white paper placed at the base of the plant was used to collect dead aphids and the tip of each leaf was shaken by hand to dislodge dead aphids still on the plants. Aphids were considered dead (Appendix 3b) when they did not move after multiple prodding with a fine-haired brush and when they had changed colour from the normal green to yellowish-grey (Phoofolo et al., 2013). For Imidacloprid treatments, samples were also collected daily even though it was applied only twice. Mortality was calculated using the following formula: $M = (N_d/N_t) \times 100$ where M=mortality (%), N_d = Number of dead aphids per plant and N_t = Total number of aphids per plant.

Temperature and rainfall data recorded at the Sir Seretse Khama International Airport (SSKIA) during the study period were used since this was the nearest weather station to BUAN.

3.1.10 Data analysis

The data on aphid mortality were subjected to a Two-Factor CRD analysis of variance (ANOVA) and if the ($f \leq 0.05$) were significant ($P \leq 0.05$), the means were separated using Tukey's Honestly significant difference test ($P \leq 0.05$) (Zar, 1984). MSTAC statistical package (Michigan State University) was used. The statistical data was not tested for normality nor transformed because there was no need to do so.

3.2. The effect of companion planting rape with garlic (*Allium sativum L.*), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes patula* L.), and basil (*Ocimum basilicum L.*) and imidacloprid application on cabbage aphid (*Brevicoryne brassicae*) populations and yield of rape.

3.2.1. Land preparation

Land preparation at the BUAN garden was done 1 week before transplanting. A tractor-mounted moldboard plough and disc harrow were used to till the soil and break large clods and level the soil surface, respectively. Twenty-four plots measuring 2m x 3m were made. Cattle manure was added as a basal dressing at the rate of approximately 30Kg/plot which is equivalent to 50 tons/ha (Bok et al., 2006) and was incorporated into the soil to a depth of 30-40 cm using a digging fork. Each plot represented one treatment replicate. Planting rows were made using a garden line (plastic rope) and 50-meter measuring tape and hand trowel was used to mark planting stations.

3.2.2. Experimental design and treatments

The experiment was factorial with treatment as factor A and sampling time as factor B with plots laid out in a randomized complete block design (RCBD) with six treatments and four blocks (Appendix 4). The plots were 50 cm apart and the blocks were separated by 1 m walkway. The treatments were as follows: T1 = garlic, T2 = marigold, T3 = basil, T4 = mint, T5 = imidacloprid, T6 = untreated control.

3.2.3. Raising seedlings

Seedlings of rape and companion plants were raised under an open space in Malotwana in January 2018 except for mint which was raised in December 2017. Seedling trays were filled up with germination medium and then sown with one seed in each hole at the depth of 5mm and seeds were covered with germination medium to the top. After sowing, watering was done using a watering can fitted with a rose. Watering was done every day in order to prevent seedlings from wilting.

3.2.4. Transplanting

Four-week old seedlings of rape, garlic, French marigold and basil and nine-week old seedlings of mint were used in the study. Companion plants were transplanted two weeks before transplanting rape to synchronize aphid infestation on rape with advanced growth stages of the companion plants when they render more effective aphid repellency. The companion plants were transplanted in two rows which were 180 m apart and 3 m long. The spacing between plants and total number of plants per row for companion plants were:10cm apart and 30 plants for garlic,45 cm apart and 7 plants for peppermint and 20cm apart and 15 plants for both marigold and basil, respectively (herbgarding.com/growinggarlic.htm,herbgardening.com/growingmint.htm, httpsi//:res.ctovdinary.com). Two rows of rape seedlings spaced at 40cm intra-row and 60cm inter-row to give a plant population of 7 plants per row were made between the two rows of companion plants. The space between rape and companion plants was 60 cm (Appendix 5). Plots were watered to field capacity before and after transplanting to avoid stressing the seedlings. All the plants in the field were managed similarly by watering once a day for four days in a week, that is, Monday, Wednesday, Friday and Sunday. Weeds were hand-pulled as soon as they emerged. Weather data (Minimum and maximum temperature (°C) and daily total rainfall (mm)) recorded at the weather station at Sir Seretse Khama International Airport (SSKIA) was provided by the Department of Meteorological Services, Gaborone, Botswana.

3.2.5. Data collection

Collection of data on total number of aphids per plant commenced three weeks after transplanting and, thereafter, twice weekly (Mondays and Thursdays between 0900 and 1100hrs) up to 11 weeks after transplanting (a total of 8 sampling times). On each sampling day, three rape plants were randomly selected for aphid counts from the top five newly developed leaves. The plants were randomly selected by picking three numbered pieces of paper from a bag out of the 14 pieces representing the plants in a plot. All aphids were removed from the rape plants using a soft haired brush onto a rectangular tray made of thick white paper, where counting was done (Pahla et al., 2014). After counting, aphids were discarded in a dumping pit and sprayed with imidacloprid in order to eliminate breeding site by killing aphids within disposed leaves. The pit was 2 m long, 1 m wide and 60 cm deep.

Assessment of total rape leaf yield was done weekly from week 5 to week 8 by harvesting and weighing the four bottom leaves of all plants per plot. Total rape yield was sorted into marketable and un-marketable leaves and the weight of each was recorded. Any leaf which was bored, yellowed, curled, dried and covered with honeydew was regarded as unmarketable. Marketable leaves were regarded as clean without any signs described for the unmarketable leaves. Rape quality loss (%) was calculated as the follows;

$$Q_{yl}= [(T_{ly}-T_{ml})/T_{ly}] \times 100$$

Where: T_{ly} is the total weight of leaf yield /plot (Kg) and T_{ml} is the total weight of marketable leaves (Kg) per plot.

3.2.6. Data analysis

Data collected were subjected to a two-factor analysis of variance (ANOVA) and if the p-value was significant ($P \leq 0.05$), the means were separated using LSD test at $P \leq 0.05$ (Freed, 1985). MSTAT-C Statistical Package (Michigan State University) was used.

CHAPTER 4.0 RESULTS

4.1. The effect of spraying botanical extracts and soap solutions on mortality of cabbage aphid on rape plants under net shade conditions

4.1.1 Main Effects of season and treatment on average aphid mortality on under net shade conditions in 2018

The average aphid mortality in summer was significantly higher than in winter ($F_{1, 72}$ = 663.85; P=0.00001) on rape under net shade conditions (Table 1).

Table 1: Effects of season on average aphid mortality on rape during a two-week period under net shade conditions in 2018 (n=48).

Season	Mean aphid mortality ± SE
Summer	52.7*± 4.16
Winter	38.7 ± 4.96
$F_{1,72}$	663.85
P	0.00001
CV (%)	8.58

* Means within a column followed by the same letter are not significantly different at (P≤0.05), Anova SE= Standard error, CV=Coefficient of variation, n=population of mean

4.1.2. Effects of treatments on average aphid mortality on rape during a two-week period under net shade conditions in 2018

The treatment effects on the average aphid mortality on rape during a two-week period under net shade conditions in 2018 were significant ($F_{11, 72}$=1145.47; P≤0.00001) (Table 2). From the ranking of the means, imidacloprid (positive control) had significantly the highest (P≤0.00001) aphid mortality, followed by 10% liquid soap, 20% basil and 20% garlic which was similar to 5% liquid soap. Liquid soap (5%) and 20% marigold were similar but significantly higher than 10% marigold and 10% garlic which were also similar but significantly higher than the two mint concentrations and 10% basil.

Table 2: Effects of treatments on average aphid mortality on rape during a two-week period under net shade conditions in 2018 (n=8)

Treatment Ranking	Mean aphid mortality± SE
1. Imidacloprid 20g/L	99.3*± 0.25
2. Liquid soap 10%	84.9 ± 0.77
3. Basil 20%	70.4 ± 1.63
4. Garlic 20%	65.8 ± 1.62
5. Liquid soap 10%	63.5 ± 3.66
6. Marigold 20%	60.6 ± 1.07
7. Marigold 10%	29.4 ± 8.21
8.Garlic 10%	24.9 ± 4.86
9. Mint 20%	18.1 ± 5.81
10.Mint 10%	17.0 ± 4.07
11. Basil 10%	15.1 ± 1.91
12. Distilled Water	0.0 ± 0.00
$F_{11,72}$	1145.47
P	≤0.00001
CV (%)	5.85
Tukey s/x , p=0.05	0.9453

* Means followed by the same letter are not significantly different (P≤0.05), Tukey's Honestly significant different test, SE= means standard error

4.1.3. Effects of season and treatments on mean aphid mortality on rape during a two-week period under net shade conditions in 2018

The season by treatments interaction had significant ($F_{11,72}$=50.96; P≤0.00001) effect on aphid mortality on rape during a two-week period under net shade conditions (Table 3). The aphid mortality on imidacloprid treated plants in summer and winter were significantly higher than other treatments. The order of ranking for the treatments shows which treatments were more effective than others against aphid. Generally, treatments in summer experiment performed better recording higher aphid mortality than in winter.

Table 3: Effects of season and treatments interaction on average aphid mortality on rape during a two-week period under net shade conditions in 2018

Ranking	Season	Spray treatment	Mean aphid mortality ± SE*
1	Winter	Imidacloprid	99.8± 0.25
2	Summer	Imidacloprid	98.8 ± 0.25
3	Winter	Liquid soap 10%	86.8 ± 0.48
4	Summer	Liquid soap 10%	83.0 ± 0.41
5	Winter	Basil 20%	74.5 ± 0.96
6	Winter	Liquid soap 10%	72.3 ± 0.63
7	Winter	Garlic 20%	69.5 ± 1.56
8	Summer	Basil 20%	66.3 ± 0.25
9	Summer	Garlic 20%	62.0 ± 0.71
10	Winter	Marigold 20%	61.5 ± 2.18
11	Summer	Marigold 20%	59.8 ± 0.25
12	Summer	Liquid soap 5%	54.8 ± 3.30
13	Winter	Marigold 10%	50.8 ± 3.09
14	Winter	Garlic 10%	37.5 ± 2.02
15	Winter	Mint 20%	33.3 ± 2.21
16	Winter	Mint 10%	27.8 ± 0.25
17	Winter	Basil 10%	19.8 ± 1.44
18	Summer	Garlic 10%	12.3 ± 0.25
19	Summer	Basil 10%	10.5 ± 0.87
20	Summer	Marigold 10%	8.0± 0.71
21	Summer	Mint 20%	6.3 ± 0.48
22	Summer	Mint 10%	3.0 ± 0.41
23	Summer	Distilled Water	0.0 ± 0.00
24	Winter	Distilled Water	0.0 ± 0.00
$F_{11,72}$			50.96
P			≤0.00001
CV			5.85%
Tukey' s test s/x, p=0.05			1.337

* Means within a column followed by the same letter are not significantly different (P≤0.05), Tukey's Honestly significant different test, SE: standard error

4.1.4. Agro-meteorological data.

The average monthly maximum and minimum temperatures inside the net shade from January to February 2018 ranged from 31.8 to 32.3 and 13.4 to 13.8°C, respectively (Table 4). The net shade was warmer in January (13.8 to 32.3°C) as compared to February (13.4 to 31.8°C). In winter the average monthly maximum and minimum temperatures inside the net shade from June to July 2018 ranged from 21.4 to 22.6°C and 2.5 to 2.8°C respectively (Table 5). The average monthly maximum and minimum outside temperatures for January to July ranged from 23.6 to 33.8°C and 3.5 to 19.9 °C (Table 6).

Table 4: Average monthly minimum and maximum temperatures inside the net shade in summer from January to February 2018

Year	Month	Average minimum temp (°C)	Average maximum temp (°C)	Overall monthly average temp (°C)
2018	January	13.8	32.3	23.1
2018	February	13.4	31.8	22.6
Overall means		13.6	32.05	29.9

Table 5: Average monthly minimum and maximum temperatures inside the net shade in winter from June to July 2018

Year	Month	Average minimum temp (°C)	Average maximum temp (°C)	Overall monthly average temp (°C)
2018	June	2.5	22.6	12.6
2018	July	2.8	21.4	12.1
Overall means		2.7	22.6	12.4

Table 6: Total rain fall, average minimum and maximum temperatures for January to July 2018 as recorded at Sir Seretse Khama International Airport Metrological Station in Gaborone.

Month	Total rainfall (mm)	Average maximum temp (° C)	Average maximum temp (° C)	Overall monthly average temp (° C)
January	2.74	19.9	33.8	26.9
February	2.87	19.4	29.4	24.4
March	1.07	17.4	28.8	23.1
April	0	13.7	27.4	20.6
May	0	7.8	25.7	16.8
June	0	3.5	23.7	13.6
July	0	3.6	23.6	13.6
Overall means	0.95	12.2	27.5	19.9

4.2. The effect of companion planting rape with garlic (*Allium sativum L.*), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes patula* L.), and basil (*Ocimum basilicum L.*) and imidacloprid application on cabbage aphid (*Brevicoryne brassicae*) populations and yield of rape

4.2.1. Main effect of treatment on cabbage aphid population on rape

Compared to the untreated control, the companion plants used in this study significantly reduced cabbage aphid population per rape plant and percentage reduction ranged from 29.3 to 78% while imidacloprid had 100% reduction (Table 7). There were significant differences in suppression of aphid populations among the companion plants compared to the untreated control with basil having the lowest population (8.67±2.37 aphids/plant) followed by marigold (10 aphids/plant), pepper mint (24.23±3.72 aphids/plant), and garlic had the highest (29.05±2.37 aphids/plant). The untreated control plants were highly infested, and the leaves were curled (Appendix 6) while imidacloprid was the most effective with no aphid infestation (Appendix 7).

Table 7: Main effect of treatment on cabbage aphid population on rape for a period of 8 weeks (n=24).

Treatment	Average Aphid counts ± SE
Garlic	29.1 ± 2.37*
Marigold	10.0 ± 1.42
Basil	8.7 ± 1.49
Mint	24.2 ± 3.72
Imidacloprid (Control)	0.0 ± 0.00
Untreated Control	41.0 ± 3.66
$F_{75,285}$	32.50
P	≤ 0.000
CV (%)	62.64

* Means in a column followed by the same letter are not significantly different, (P≤0.05), Tukey's Honestly significant different test, SE: standard error

4.2.2. Average weekly aphid counts for each treatment for a period of 8 weeks

Comparison of weekly average numbers of aphids per plant for the treatments showed significant differences among the treatments and similarly comparison of the treatments across the sampling times (Table 8a). In week 1 aphid population on rape companion cropped with basil, marigold and mint were similar but significantly ($F_{5, 41}$=11.76, P=0.001) lower than garlic. The imidacloprid and untreated controls had the lowest and highest populations, respectively. There were significantly high aphid counts recorded in week 4, followed by week 5 then weeks 3, 6, and 7 (which were not significantly different from each other). Week 1 had the lowest aphid counts followed by weeks 2 and 8. Similarly, the aphid population for marigold per week were significantly different ($F_{7, 55}$=5.19; P=0.0001). Marigold in week 4 had significantly high aphid population followed by week 5 then all the other weeks (1, 2, 3, 6, 7 and 8) were not significantly different from each other. Similar pattern of aphid occurrence was observed on basil ($F_{7, 55}$=9.22; P=0.0001), mint ($F_{7, 55}$=5.87; P=0.0001) and water (Control) ($F_{7, 55}$=41.02; P=0.0001). The chemical treatment using Imidacloprid resulted in no aphids observed for all the weeks.

The weekly aphid population for each treatment were compared for 8 weeks' period of the study (Table 8a). This table shows within treatment comparisons of the weekly aphid numbers on rape crops which were intercropped with companion plants during the entire experimental period. The results revealed that the weekly aphid numbers for the treatments were significantly different ($F_{7, 332}$=55.13; P=0.0001). The weekly aphid population for basil, from week 1 to week 8, were significantly different ($F_{7, 55}$=24.06; P=0.0001). Figure 1 depicts population dynamics of aphids on rape plants for each of the treatments used in the study for a period of 8 weeks. Low aphid numbers were recorded on rape crops at the beginning of the experiment (Week 1) in all the treatments. The numbers in all the treatments started to increase on the second week of observation and the increment continued and reached the peak on week 4 of the observation except for garlic which reached the peak on week 5 of the observation.

Table 8b is a summary of the ranking of the botanicals in terms of mean aphid counts where the lowest number was rated as number 1 and highest as 4. Overall performance ranking was as follows: 1. basil, 2. marigold, 3. mint and 4. garlic.

Table 8a: Effect of mean aphid count for treatments per week for a period of 8 weeks

Weeks	Treatment Means ± Standard Error						Statistics
	Garlic	Marigold	Basil	Mint	Imidachloprid	Untreated control	
1	4.6±2.02	1.9±1.34	1.0±0.68	3.3±1.29	0.0±0.00	11.9±1.37	($F_{5,41}$=11.76; P=0.001)
2	18.5±1.85	7.6±1.46	9.0±2.24	13.5±1.82	0.0±0.00	25.9±1.59	($F_{5,41}$=34.00; P=0.001)
3	31.9±7.19	6.9±3.27	6.4±2.63	28.6±7.73	0.0±0.00	52.5±7.73	($F_{5,41}$=12.55; P=0.001)
4	58.9±4.30	25.8±8.17	30.5±7.46	67.1±22.28	0.0±0.00	95.5±2.91	($F_{5,41}$=12.65; P=0.001)
5	48.5±2.90	16.4±1.51	9.1±2.30	38.1±3.43	0.0±0.00	65.9±6.77	($F_{5,41}$=51.83; P=0.001)
6	28.3±3.48	8.0±0.96	4.8±1.03	14.6±1.45	0.0±0.00	33.4±4.37	($F_{5,41}$=30.86; P=0.001)
7	23.1±1.38	6.6±0.99	5.1±0.44	16.0±1.65	0.0±0.00	24.4±3.90	($F_{5,41}$=27.56; P=0.001)
8	18.6±0.94	6.9±1.56	3.5±0.63	12.6±1.21	0.0±0.00	18.3±1.58	($F_{5,41}$=49.23;P=0.001)

* Means within a row followed by the same capital letter are not significantly different (Tukey's test, P≤0.05)
* Means within a column followed by the same small letter are not significantly different (Tukey's test, P≤0.05)

Table: 8b. The weekly ranking of the effectiveness of treatments (from the best to the poorest) during the 8-week period

	Weekly ranking of each treatment			
Week	Garlic	Marigold	Basil	Mint
1	4	2	1	3
2	4	1	2	3
3	4	2	1	3
4	3	1	2	4
5	4	2	1	3
6	4	2	1	3
7	4	2	1	3
8	4	2	1	3
Overall Rank	4	2	1	3
Statistics	$F_{7,55}$=24.06; P=0.0001	F7,55=5.19; P=0.0001	$F_{7,55}$=9.22; P=0.0001	$F_{7,55}$=5.87; P=0.0001

The aphid numbers then started to decline at week 5 and remained constantly low from week 6 until the end of the experiment except for garlic, where the decline in numbers of aphids started at week 6 and it remained constantly low from week 7 until the end of the experiment (Figure 2). The treatments were seen to have significant increase and decline of aphid numbers except for imidacloprid (control) which did not record any aphids. The aphid numbers were higher in untreated control, garlic and mint. This support what was shown in Figure 1, that water (control), garlic and mint generally had high aphid numbers especially at week 4 when compared to marigold, basil, mint and control (imidacloprid).

Figure 1 reveals the rate at which the numbers of aphids per plant for each treatment increased during the 8-week period. Therefore, the more the aphids found per treatment, the lesser the efficacy of the treatment in controlling the aphids and vice versa. Growth rate was used to test the associations between treatment effect and aphid population. The more effective the treatments were, the lower the population development of the insect pests which implies low population growth rate. Imidacloprid (control), marigold and basil significantly reduced aphid population growth rate than garlic, mint and untreated control. No aphids were observed on plants treated with Imidacloprid. The rate of increase of control, garlic and mint was very high (Figure 2). Rate of aphid increase was low on imidacloprid followed by marigold and then basil.

4.2.4. The effects of companion planting rape with garlic, peppermint, French marigold, and basil and imidacloprid application on rape leaf yield

Compared to the untreated control, companion plants used in this study significantly increased both total ($F_{3,72}$ = 33.24, P=0.0001) and marketable ($F_{3,72}$ =15.86, P=0.0001) rape leaf yield and percentage increase ranged from 5 to 37.1% and 13 to 1266%, and imidacloprid had the highest increase of 40 and 1393 %, respectively (Table 9). Among the botanical companion-planted rape, significant differences ($p \leq 0.05$) in total leaf yield were observed in rape with basil (2.18kg/plot) followed by French marigold (2.0kg/plot) and mint (1.95kg/plot). Companion planting rape with garlic did not significantly increase total yield compared to the untreated control. Similar trend was observed for marketable leaf yield. Quality yield losses ranged from 0% in imidacloprid treated plants (Appendix 7) to 90.6% in the untreated control plants (Appendix 6 and 8). Among the botanicals yield losses in rape companion-planted with basil, mint and marigold were 6.0%, 16.9% and 20.5% while garlic and the untreated control were 89.8% and 90.6%, respectively.

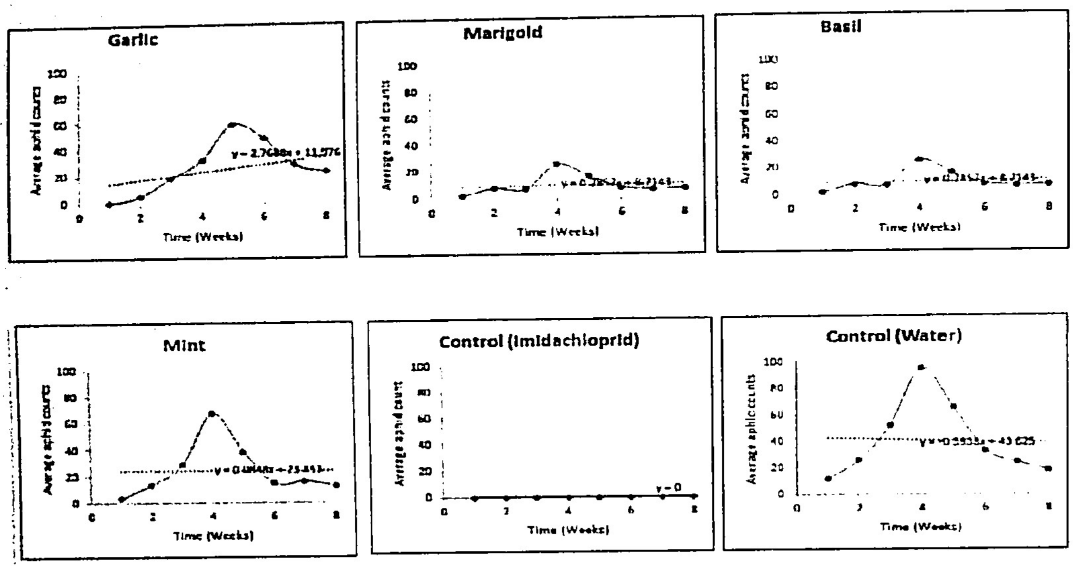

Figure 1: Population dynamics of aphids for each treatment for a period of eight weeks

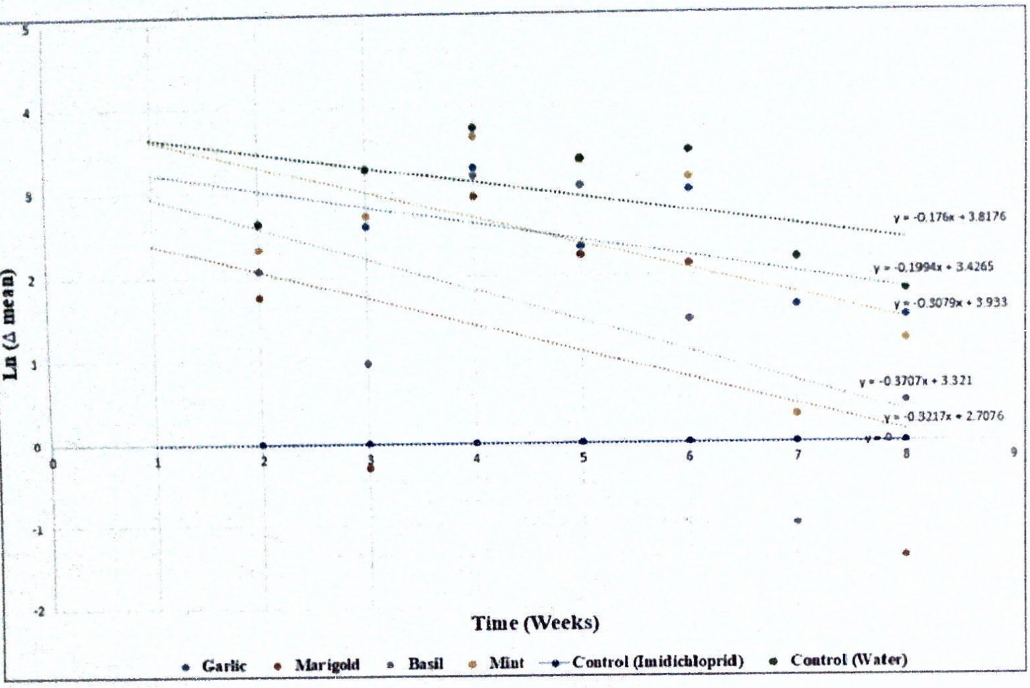

Figure 2: Rate of decrease of aphids per week for each treatment

Table 9: Effects of treatment type on rape leaf yield (n=16).

Treatment	Total leaf yield (Kg/plot)	Marketable leaf yield (Kg/plot)	Quality yield loss (%)
Garlic	1.7[a] (5.0%)[$]	0.2 (13.0)	89.8[β]
Marigold	2.0 (25.0)	1.6 (960.0)	20.5
Basil	2.2 (37.1)	2.1 (1266.0)	6.0
Mint	2.0 (22.0)	1.6 (147.0)	16.9
Imidachloprid	2.2 (40.0)	2.2 (1393.0)	0
Control	1.6 (0.0)	0.2 (0.0)	90.6
LSD value	0.08922	0.07397	
$F_{5,72}$	63.57	1154.43	
P	≤ 0.0001	≤ 0.0001	
CV (%)	6.81	8.31	

[a]Means in a column followed by the same letter are not significantly different ($P\leq 0.05$) LSD test

[$]Numbers in brackets are percentage increase in yield calculated as leaf yield in treated plots minus leaf yield in untreated control plots/ yield in untreated control plots multiplied by 100

[β] Quality yield loss was calculated as: {(total leaf yield(kg)/plot - marketable leaf yield (kg)/plot)/total leaf yield (Kg)} x 100

4.2.5. Effect of treatment type and sampling time on rape leaf yield

Compared to the untreated control, total and marketable leaf yields of rape treated with the synthetic insecticide were significantly higher and increased with time of sampling from 2.07Kg/plot (week 5) to 2.50kg/plot (week 8) with no loss in quality and this was followed by basil with total yield of 2.03kg/plot (week 5) to 2.38Kg/plot (week 8) and quality loss of up to 11.9 % and mint with 1.73Kg/plot (week 5) to 2.00kg/plot (week 8) with quality loss of up to 23.7% (Table 11). Decline in total leaf yields with time were observed for marigold with 2.03kg/plot (week 5) to 1.80kg/plot (week 8) with up to 31.0 % loss, garlic with 1.74kg/plot (week 5) to 0.95kg/plot (week 8) with up to 93.7 and untreated control with 1.81kg/plot (week 5) to 0.75kg/plot (week 8) with up to 91.6% loss in quality. Similarly, the yield of marketable leaf was highest in imidacloprid treated plants followed by that of rape intercropped with basil, mint marigold, garlic and untreated control.

Table 10: Effect of treatment type and sampling time on rape leaf yield (n=4).

Treatment	Sampling time (weeks after planting)	Total leaf yield Kg/plot	Marketable leaf yield (Kg/plot)	Quality yield loss (%)
Garlic	5	1.7[a] (0)[s]	0.2 (0)	87.9
	6	2.0 (14.9)	0.2 (9.5)	88.5
	7	2.0(14.9)	0.2 (-9.5)	90.5
	8	1.0 (-45.4)	0.1 (-71.4)	93.7
Marigold	5	2.0(0)	1.4 (0)	31.0
	6	2.0 (-1.48)	1.9 (37.1)	4.4
	7	2.0 (-1.48)	1.5 (10)	23
	8	1.8 (-11.3)	1.5 (6.4)	17.2
Basil	5	2.0(0)	1.9 (0)	7.9
	6	2.0 (-1.48)	1.9 (3.2)	3.5
	7	2.4 (15.8)	2.1 (10.7)	11.9
	8	2.4 (17.2)	2.3 (24.6)	2.1
Mint	5	1.7 (0)	1.3 (0)	23.7
	6	2.0 (15.6)	1.5 (15.9)	23.5
	7	2.1 (19.1)	1.8 (35.6)	13.1
	8	2.0 (15.6)	1.9 (40.2)	7.5
Imidachloprid	5	2.1(0)	2.1 (0)	0
	6	2.2 (3.9)	2.2 (3.9)	0
	7	2.3 (8.7)	2.5 (8.7)	0
	8	2.5 (20.8)	2.5 (20.8)	0
Control	5	1.8 (0)	0.2 (0)	89.5
	6	2.2 (28.8)	0.2 (-5.3)	91.6
	7	1.8 (-0.6)	0.2 (-10.5)	90.6
	8	0.8 (-58.6)	0.1 (-68.4)	92
$F_{15,72}$		24.60	10.34	
P		≤ 0.0001	≤ 0.0001	
LSD Value		0.178	0.148	
CV (%)		6.81	8.31	

[a] Means for total and marketable yield whose difference is >0.178kg/plot and >0.148kg/plot, respectively are significantly different ($P \leq 0.05$) LSD test

[s] For each treatment numbers in brackets are percentage increase in total yield calculated as leaf yield for a particular sampling week minus leaf yield for week 5 / yield for week 5 multiplied by 100

CHAPTER 5.0 DISCUSSION

5.1 The effect of spraying botanical extracts and soap solutions on mortality of cabbage aphid on rape plants under net shade conditions

Plants have produced many secondary chemical compounds, as they evolved, to defend themselves against herbivores and pathogens and this has led to some of them having been used historically for pest management (Markouk et al., 2000; Pino et al., 2013; D'Incao et al., 2013 Miresmailli and Isman 2014; Pavela 2016). This study aimed at screening and selecting some locally available herbs for their extracts which have toxic effects thus having potential for use as botanical insecticides. Since these plants are eaten by humans and used for pharmacological activities because of their natural compounds, their extracts have low or no hazardous effect on humans or other animals.

Significantly higher cabbage aphid mortality on rape treated with various botanical extracts under net shade was observed in summer than in winter. This could be due to high temperatures in summer with overall average maximum temperatures of 32.05°C which is higher than the favourable temperature for the cabbage aphid growth and survival of 13.3 to 22.8°C (Wellings and Dixon, 1987, Kessing and Mau, 1991). However, in the winter there was less mortality as temperatures in net shade were cooler with an overall mean temperature of 12.4°C which is reported to favor growth and development of cabbage aphid. The results are in line with Munthali et al. (2004) who reported that in Botswana cabbage aphid populations tend to build up quickly on infested plants during cool to warm weather conditions suitable for growth of rape. In this study, the January and February 2018 temperatures ranged from 13.6-32.05°C (monthly average of 29.9 °C) while the June to July 2018 temperatures ranged from 2.7-22.6 °C (monthly average of 12.4 °C). These findings concur with to those of Debaraj et al., (1994) who reported that *B. brassicae* population and average temperature are positively correlated. These observations are also in agreement with those of Kotwal (1981) who reported that low temperatures negatively influence *B. brassicae* population. They reported minimum and maximum temperature range of 6-13°C and 12-26°C, respectively, with the former negatively affecting aphid growth and development.

Regardless of season, cabbage aphid exposed to the higher concentration (20%) of botanical extracts had significantly higher mortality than those subjected to the lower concentration (10 %) indicating that using 200g of botanicals/L was more effective. Overall, the liquid soap performed better than the plant extracts and among the plant extracts basil was the best followed by garlic, marigold and lastly mint in reducing aphid populations. Our results of 20% having higher effectiveness than 10% agree with Phoofolo et al. (2013) in Lesotho, who reported that an increase in plant extract concentration resulted in an increase in the percentage of aphid mortality. It has further been reported that the higher the concentration of bioactive compounds, the higher the toxic, antifeedant or deterrent effects of botanicals against cabbage aphids (Nahusenay and Abate, 2018). It has been reported that many plants naturally have unpalatable substances which have negative effect on aphid development such as antifeedant, oviposition deterrent, insecticidal, ovicidal and insect growth regulators against insect pests (Isman, 1997). All the three botanicals had toxic effects on cabbage aphid since the mortality caused by mint (least effective botanical) was still significantly higher than distilled water.

The findings of this study are also supported by Ezena et al. (2016), who reported that botanicals considerably reduced number of aphids compared to tap water but does not agree with their finding where conventional insecticide sunhalothrin was poorer than the botanicals. Similarly, a study done by Nahusenay and Abate (2018) reported that treating cabbages with botanical extracts was more economical than using dimethoate or not controlling at all. Sarwar (2015) reported that some botanicals act very quickly to stop cabbage aphid from feeding. A good botanical pesticide should protect a crop against target pests to levels below economic threshold (Mwine et al., 2013). Synthetic pesticides like imidacloprid have high knockdown effect resulting in higher mortality than botanicals and are applied less frequently while the botanical extracts have no knockdown effect must be applied more frequently (Isman et al., 1997, 2006). In our study imidacloprid was sprayed twice during the experimental period while botanicals extracts were sprayed daily. The performances of each of the controls (imidacloprid and distilled water) were the same in summer and winter while basil, garlic and marigold generally performed better in winter than in summer. This could be due to volatility of bioactive compounds under high and low temperatures with more volatility in summer than in winter. Partridge and Borden (1997) reported that the potential of bio-pesticides varies with meteorological conditions. Aphids, just like other insects have limited ability to regulate their body temperatures above or below ambient, therefore, they are affected by environmental thermal conditions (Alford et al., 2014). This could also explain why the mortalities were higher in summer that the winter.

5.2. The effects of companion planting rape with garlic (*Allium sativum*), peppermint (*Mentha canadensis* L.), French marigold (*Tagetes spatula* L.) and basil (*Ocimum basilicum* L) on cabbage aphid (*Brevicoryne brassicae*) populations on rape plants.

The population of cabbage aphid was lowest on rape treated with imidacloprid followed by rape companion-planted with basil, marigold, mint, garlic and untreated control had the highest population (Table 7). Tiroesele and Matshela (2015) conducted a field study and found that basil intercropped with kale (*Brassica oleracea var. acephala*) had the least cabbage aphid infestation followed by garlic and marigold. The two studies agree that basil is the best but differ in the ranking between garlic and marigold. However, this study is in line with the results of Pahla et al., (2014) who did a similar experiment where they intercropped rape with garlic and onion separately and rape with garlic and onion combined, and their results showed that intercropping rape with garlic and onion combination had significant ($P<0.001$) effect on rape fresh mass, leaf damage and aphid population. Intercropping rape with garlic alone recorded the lowest aphid population, least leaf damage and highest leaf mass as compared to all other treatments. The volatile substances (allicin) which is responsible for pesticidal properties are mostly contained in the garlic cloves. However, results from intercropping rape with garlic and onion combination were not significantly different from intercropping rape with garlic alone. Basing on the research findings, it was concluded that intercropping rape with garlic is an effective practice in the control of aphids in rape recommendable for adoption by resource-poor smallholder vegetable producers.

In this study, basil had the strongest aroma whose chemical composition according to Kim et al. (2012), consists of 1, 8cincol, linalool, citral, methyl chavicol (estragole), eugenol and methyl cinnamate which tend to repel aphids hence reducing the infestation levels. Basil oil has also been reported to be toxic resulting in death of *Aphis craccivora* as well negatively affect fecundity, longevity and nymphal development (Sammour et al., 2011). Field observations showed that basil had a well-developed canopy (Appendix 9) and the plants were the same height or taller than rape thus increasing its efficiency in repelling aphids.

Even though garlic is said to repel aphids, it was observed from this study that it was not as effective as basil in pest control. This might be because according to Huang et al. (2000), garlic is a cool season crop and it did not produce enough smell to repel aphids as basil and marigold. However more of the volatile substances (allicin) which is responsible for pesticidal properties are mostly contained in the garlic cloves (roots) which did not produce enough smell to repel aphids because they were underground and have to be bruised in order to release the volatiles. Allicins are responsible for the pesticidal and repellence properties of garlic against aphids (Tada et al, 1988, Mudzingwa et al, 2013). This is due to the presence of sulphur containing amino acid derivatives in garlic which, in the presence of oxygen, reacts with the enzyme allinase to form allicin and other sulphur compounds. Allicin breaks down into Diallyl disulphide, which is largely responsible for the pungent garlic odour. This agrees with findings by Sarker et al., (2007) who noted that garlic intercrop treatments showed positive effectiveness as evidenced by lowest aphid population because of the high levels of volatile substances (allicin) that repel aphids. Simmonds et al (1992) reported that *Allium* spp. are very effective antifeedant and strong pungent repelling action. Therefore, the differences in the efficacies of the treatments are a result of the differences in the physical properties and potency of the active compounds in the various treatments used. These results are similar to Asare-Bediako (2010) who reported that onion and garlic intercropping systems were also found to have repellent effects on diamond back moth to reduce pest populations because the companion plants act as physical barriers to the movement of the insect pest, natural enemies are more abundant and/or the chemical or visual communication between DBM and the cabbage is disrupted. The poor performance of garlic in this could be due to the poor growth of the plants (Appendix 10) due to high temperatures during the study since garlic favours cool growing conditions. By the end of the study garlic plants were still small and did form a close canopy around the rape plants compared to basil and marigold.

Aphid populations were also low on marigold intercrop and this could have been due to marigold providing alternate habitation, alternate food or intermediate hosts for predators as reported by other workers. Marigold provides more nectar and pollen during its flowering stage for natural enemies, which may lead to the attraction of more predator species, thus leading to an overall increase in natural enemies in an intercropping system. Similar results were also reported by Held et al. (2003), on white cabbage intercropped with marigold. Marigold grew vigorously during the study and its canopy may have shaded and negatively affected rape growth (Appendix

11) in addition to protecting the rape from aphid infestation. The results of this study suggest that farmers could use plants which can attract insect predator in their vegetable crops to control pests such as aphids.

Mint however was the third most effective companion plant in comparison with others. Finch et al. (2003), reported that mint did not repel the onion fly or cabbage root fly (D. *radicum*), but rather interrupted their host finding and selecting. The most abundant compounds responsible for this were: terpenes (with carvone, dihydro-carvone, D-limonene and eucalyptol or 1, 8-cineole as the most represented); alcohol (mainly 1-octen-3-ol and 3-methyl-1-butanol); ketones (e.g. 3-octanone); esters (e.g. 2-methyl-ethyl ester-butanoic acid) (Gochev, 2008). Appendix 10 shows that mint plants which are perennial did not grow well or were still young during the study and their canopy was way below that of rape. This could have contributed to the poor performance compared to the basil and marigold.

The highest aphid populations recorded in the untreated rape throughout the sampling period concur with findings by Minja (2001) who observed that if aphid population is left unchecked, it grows exponentially and further growth is only limited by food source besides other selection pressures. Mudzingwa et al., (2013) reported that the rapid aphid proliferation could be attributed to their rapid development time (8-12 days) from first instar nymph to adult, possible reproduction in absence of males and extended reproductive life span of up to 30 days and fecundity of 5-6 nymphs day-1. The high aphid population in untreated rape plants also complements findings by Hai-bo (2013) who observed that mono-cultured plants show more aphids than intercrops as a result of lack of any protective measure against pests.

The weekly cabbage aphid counts on rape intercropped with the botanicals were generally lower than on the control but higher than those sprayed with imidacloprid and the aphid populations increased with time up to the 4th week before declining (Table 8 and Figure 1). Low aphid accounts recorded at the beginning of the experiment could be because the crops were still too small to be located and attacked while populations declined towards the end due to the protection of the larger canopies of botanicals. During the experimental period, it was observed that trace amount of rainfall coupled with cool temperatures and cloudiness favoured the aphid incidence between February and July, with temperature range from 3.6 to 33.8 °C. Wellings and Dixon (1987) reported that average temperature of 18.06 °C (maximum of 22.8 °C and minimum of 13.31 °C) under the influence of high relative humidity, with a range of 80.7% to 86.5% provided favourable conditions for aphid incidence. The increase in aphid population could be due to increase in foliage and growth of the plant which provided good quality plant food and enough surface area for the pests to feed on. These findings are in line with those of Hasan et al. (2009), who reported that aphid population becomes higher during the vegetative stage of growth. Increase in aphid population might be due to high temperatures experienced during the experimental period while decrease in population numbers towards the end of the experiment might be due to cold temperatures in winter season and maturity of the botanicals.

Except for imidacloprid treated plants, weekly overall mean aphid counts for basil, marigold, garlic and mint were significantly different with the populations peaking at week 4 of sampling and giving typical bell-shaped population growth curves in Figure 1. The performance ranking of the treatments during the sampling periods was consistent with basil as number 1 followed by marigold, garlic and mint. However, the significantly consistent lower aphid counts in intercropped rape than control showed that as the botanical plants grew, the concentrations of volatile compounds in the air increased and may even have affected the control plots which were in proximity.

In this study the basil and marigold were mature and flowering at week 4 and were releasing the strong smell to repel the aphids and their smell might have attracted natural enemies for aphids hence their reduction in number. This observation was also reported by Song et al. (2012) who stated that marigold produces volatiles that attract both parasitic and predatory natural enemies of aphids such as parasitic wasps, ladybugs and lacewings. These companions also provided habitants and nectar for the aphid natural enemies. Szendrei et al. (2009) reported that basil produces a strong smell which deters pests by putting them off crops like brassicas. High aphid populations observed in untreated control resulted in curled, bored, deformed leaves. Garlic was effective as a spray but not as a companion crop probably because the cloves were not fully developed by the end of the study. In addition, garlic is effective when the cloves are crushed to release allicins into the air so in the intercrop the release of allicins from the underground bulbs into the surrounding air could be minimal. Pahla et al. (2014) observed that there were no significant differences on aphid population amongst all treatments in the first week of data collection (week 3 after planting rape). They said that this could have been a result of the stage of development of the intercrops (garlic and onion) which was still premature to render any notable repellent effect on pests.

5.2.1 The effects of companion planting rape with garlic, peppermint, French marigold, and basil and imidacloprid application on rape leaf yield

The relatively higher total leaf yields (marketable and unmarketable) from companion-planted rape than the control obtained in this study agreed with findings of Pahla et al. (2014) who reported that rape intercropped with garlic alone or in combination with onions had significantly higher (P=0.001) leaf yield than the mono-cropped rape. The companion planting significantly reduced leaf damage by aphids resulting in higher marketable yield and low reduced quality loss. Imidacloprid resulted in the highest marketable leaf yield because of its fast knockdown effect which did not allow aphid build up. Aphid damage is mainly caused by the toxic saliva which induces leaf distortions in addition to the sucking of the plant sap (Townsend, 2013). The leaf distortion reduces the surface area (leaf area index) to absorb the sunlight for photosynthesis. This result in reduced photosynthates made to support plant growth and development thus reducing the growth of the plants. This could have contributed to the lower fresh marketable leaf yield on highly infested plants as compared to the plants with less infestation. The higher the aphid infestation the higher the amounts of assimilates extracted from the plants by the aphids. Mudzingwa et al. (2013) stated that assimilates were responsible for cell division and cell elongation which results in growth, development and yield of the crop. Companion planted rape had various degrees of damage depending on the effectiveness of the volatiles released by each companion plant with basil (6%) having significantly least damage compared to mint (16.9%) marigold (20.5%) and garlic (89.8%). According to Minja et al. (2001) and Asare-Bediako (2010), the higher the population of aphids, the greater the degree of leaf damage and loss in marketable yield.

The most common damage symptoms in this study were yellowing, curling and scotching of leaves and general stunting of the plants. Some of the symptoms could have been due nutrient deficiencies since kraal manure was only applied once. Some companion plants like marigold have large canopies upon maturity and may shade the rape. This could explain why marigold performed poorer than mint in the field while in the net shade study marigold was better than mint. Also average marketable yields of marigold decreased not only because of aphid infestation, it was observed that marigold plants were taller than rape and had a closed canopy which shaded rape. The results in this study were in line with (McClure and Frank., 2015, Finch et al., 2003) who reported that marigolds appear to be allelopathic to other neighbouring plants. Due to the possible allelopathic effects, it's probably best to plant marigolds and vegetables in separate beds. Garlic performed poorly resulting in yield loss like the control probably because there was very little allicin released from the leaves to affect aphid populations. As discussed above, allicin is released in high concentrations following injury of leaves and cloves.

Weather parameters play major role in determining the crop growth, development and yield because weather strongly influences the physical expression of genetic potential of the crop. Any significant deviation of this parameter from the optimum value became detrimental for the crop productivity. Generally, about 67 per cent variation of any crop is governed by prevailing weather condition and 33 per cent by other management factors. Weather has direct effect on growth and development of plants. All the physio-chemical and biological activities of the plants are governed by the weather variables prevailing in that in that area (Khavse et al., 2014).

Week 6 to 8 corresponded with end of March and April. The temperature around this period was 28 °C and it has been observed that in this study rape yield in this period was very high which implies that the temperatures during this period were conducive for crop growth and development. Angadi et al. (2000) also observed high yield of rape at 28 °C than at 35 °C, the crop had high harvest index. The authors also stated that temperatures around 35 °C cause plant stress hence low productivity. Similarly, rape companion planted with marigold, basil, garlic, mint and imidacloprid had good weekly marketable leaf yields from week 6 to 8.

The studies have been carried out on some plants such as garlic, onion, and basil that have semiochemical properties (Senthil-Nathan et al., 2005), marigold and basil (Tiroescle and Matshela 2015). These plants are also used as border plants to repel insects from cultivated crop. Garlic and onion produces pungent alliaceous compound, ally-epropyle-disulphide which is responsible for their repellent attribute (Baidoo et al., 2012a). Garlic is known to have anti-feedant, insecticidal and repellent properties which contributed to lower number of pests on the garlic spraying. Basil was observed to be producing the strongest aroma which according to Kim et al. (2012), the volatile components are 1, 8 cineol, linalool, citral, methyl chavicol (estragole), eugenol and methyl cinnamate which tends to repel aphids hence reducing the infestation and number of aphids on rape plants. However, mint has abundant compounds responsible for interrupting the insects host finding and selection (Finch and Collier 2000). The most abundant compounds responsible for this were; terpenes (with carvone, dihydro-carvone, D-limonene and eucalyptol or 1, 8-cineole as the most represented); alcohol mainly (1-octen-3ol and 3-methyl-1butanol); ketones (e.g. 3-otanone); esters (e.g. 2-methyl-ethyl ester-butanoic acid) (Gochev et al., 2008). Marigolds contain insecticidal components that are effective against pest's species especially stored products. The plant acts as a repellent, antifeedant and has fumigant effects on target pests. Marigold extracts contains α-terthienyl and bithienyl as the active insecticidal components involved in protection against pests (Morallo-Rejesus and Decena 1982)

The demand for botanicals is poised to grow due to an increasing shift in consumer demand for safe food and increasing organic farming (Sola et al., 2014). The study will help, small holder farmers realize the importance of botanical plants and they would be required for adopting the use of botanical plants and encouraged to cultivate them in a large scale. In addition, these products are safe to users as their discoloration doesn't affect the quality of the product as evidenced by the fact that they are used as culinary spices and herbs (Tiroesele et al., 2014). The use of soap solutions and detergents as adjuvants, improves both the active ingredient solubility in the formulation and its physical and biocidal performance e.g. (wetting, properties on plant or insect cuticle). Co-adjuvants are added directly to the tank before applications with the same purposes (Curkovic, 2007). However, repeated use of soaps and detergents has proved in several cases that it can provide a control equivalent to conventional insecticides, furthermore detergents and soaps can be used as co-adjuvants for conventional and biological pesticide (Curkovic, 2016).

CHAPTER 6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In conclusion, the results of the net shade study indicated significantly higher aphid mortality in summer than in winter and imidacloprid resulted in the highest aphid mortality followed by the high concentrations of sunlight liquid, basil, garlic, marigold and mint. Therefore, spraying some of the botanical extracts such as basil and garlic and soap solutions had effect on mortality of cabbage aphid on rape plants under net shade conditions. This shows their promising potential as bio-pesticides. This study used botanical extract concentrations of 10 and 20% and in future, higher concentrations should be tested for their LC_{50}. Based on the findings of the study, the null hypothesis is rejected and accepts the alternative hypothesis which states that spraying botanical extracts and soap solutions significantly increases mortality of cabbage aphid on rape.

The field experiment study also showed that imidacloprid significantly controlled the aphid populations compared to other treatments, followed by basil, marigold, mint and then garlic. Untreated control had the highest aphid population. Therefore, companion planting rape with some plants such basil, French marigold and imidacloprid application reduced cabbage aphid populations and improved yield of rape, thus showing their potential to control cabbage aphids. These findings, therefore, lead to rejection of the null hypothesis and accept the alternative hypothesis which states that companion planting rape with botanical plants such as garlic, peppermint, French marigold, and basil and imidacloprid application significantly lower cabbage aphid populations and increase yield of rape.

6.2 Recommendations

This study has shown the potential of botanical plants, both as extracts and companion plants, to reduce aphid population and its effects on rape. Therefore, they should be incorporated as constituents of a pest management strategy especially in vegetable production to control aphids. This was more evident with basil both as an extract and as a companion plant. Other companion plants such as marigold have also shown promising results. Liquid soap has also shown promising results to reduce cabbage aphid effects and population. It is therefore, recommended that smallholder vegetable farmers who cannot afford expensive and dangerous synthetic insecticides should utilize these plants and soap solutions for pest management, in addition to selling them for profit.

Suggestions for further research

The limitations of this study were time, funding and the fact that other locally available botanicals could not be tested. The following are therefore suggested areas for further study:

1) The study to be repeated on a large scale to validate these results under typical farm conditions against not only aphids but the whole insect herbivore complex of brassicas and other commonly grown vegetables in Botswana.
2) More botanicals and other locally available companion plants should be assessed for the control of major insect pests of rape.
3) Determination of the mechanisms of the active ingredients in local botanicals.

4) Investigate marketing of the vegetables sprayed with botanical and conventional insecticides

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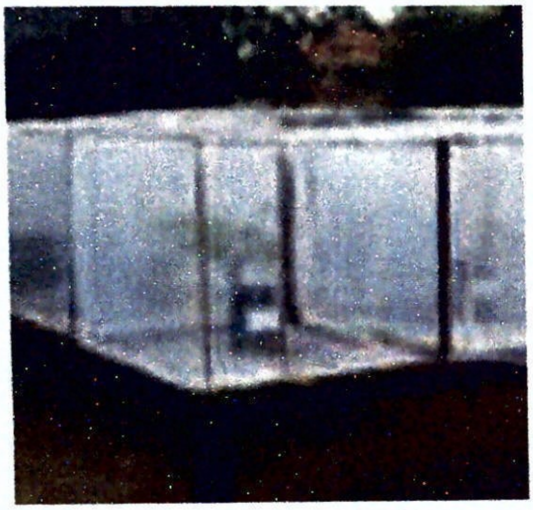
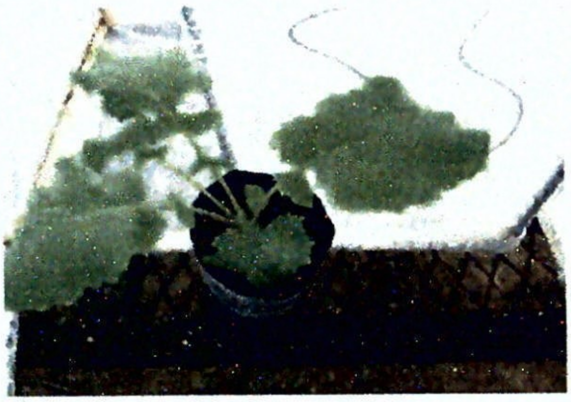
APPENDICES

Appendix 1: 40 x 40 x 32 cm insect-proof cage covered with mesh size lumite screen, with a potted rape plant inside



Appendix 2: Rape plant grown in the plastic pot

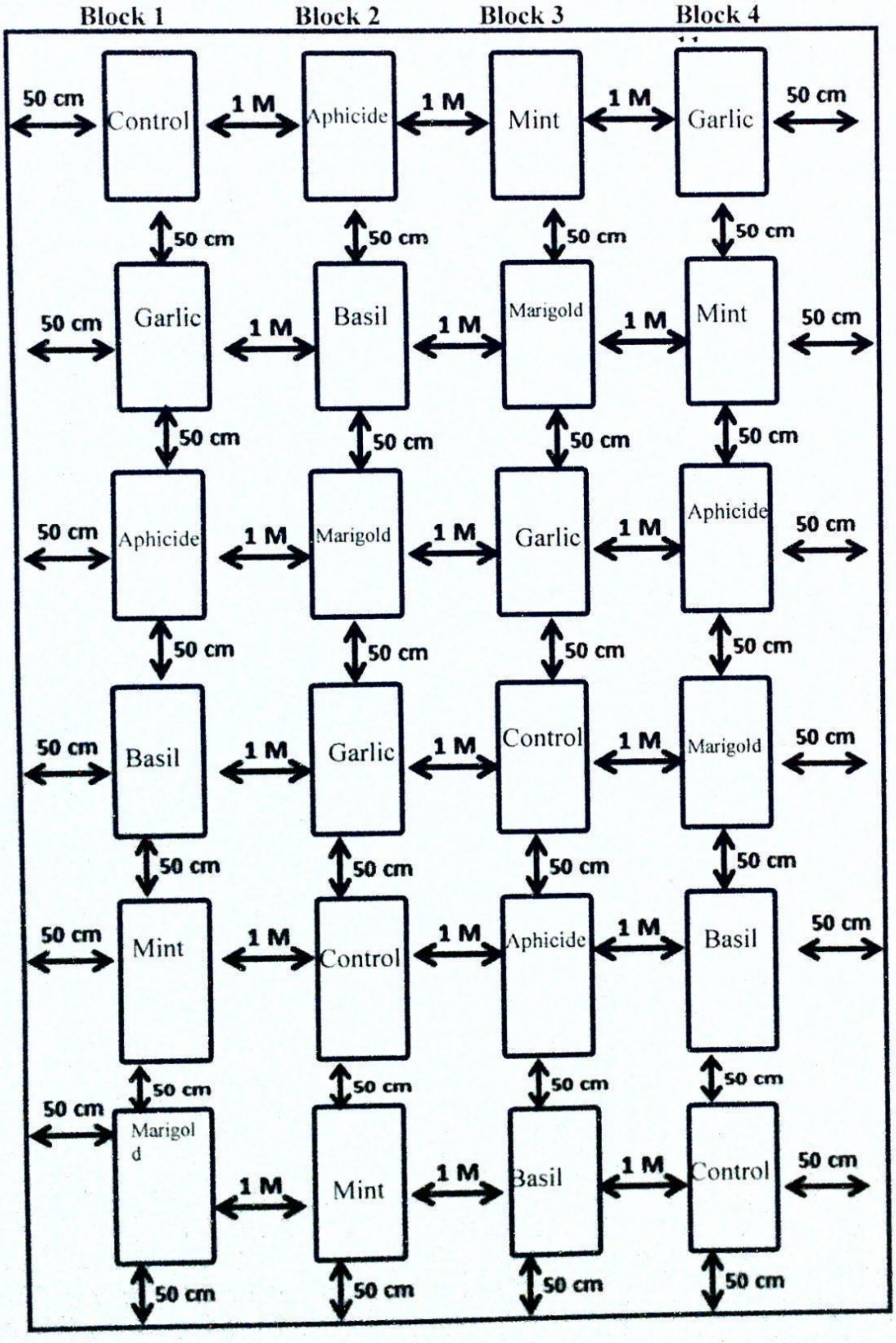
Appendix 3: Aphids on 5- leaf stage rape in a cage a) and close-up showing aphids on a 5- leaf stage rape b)



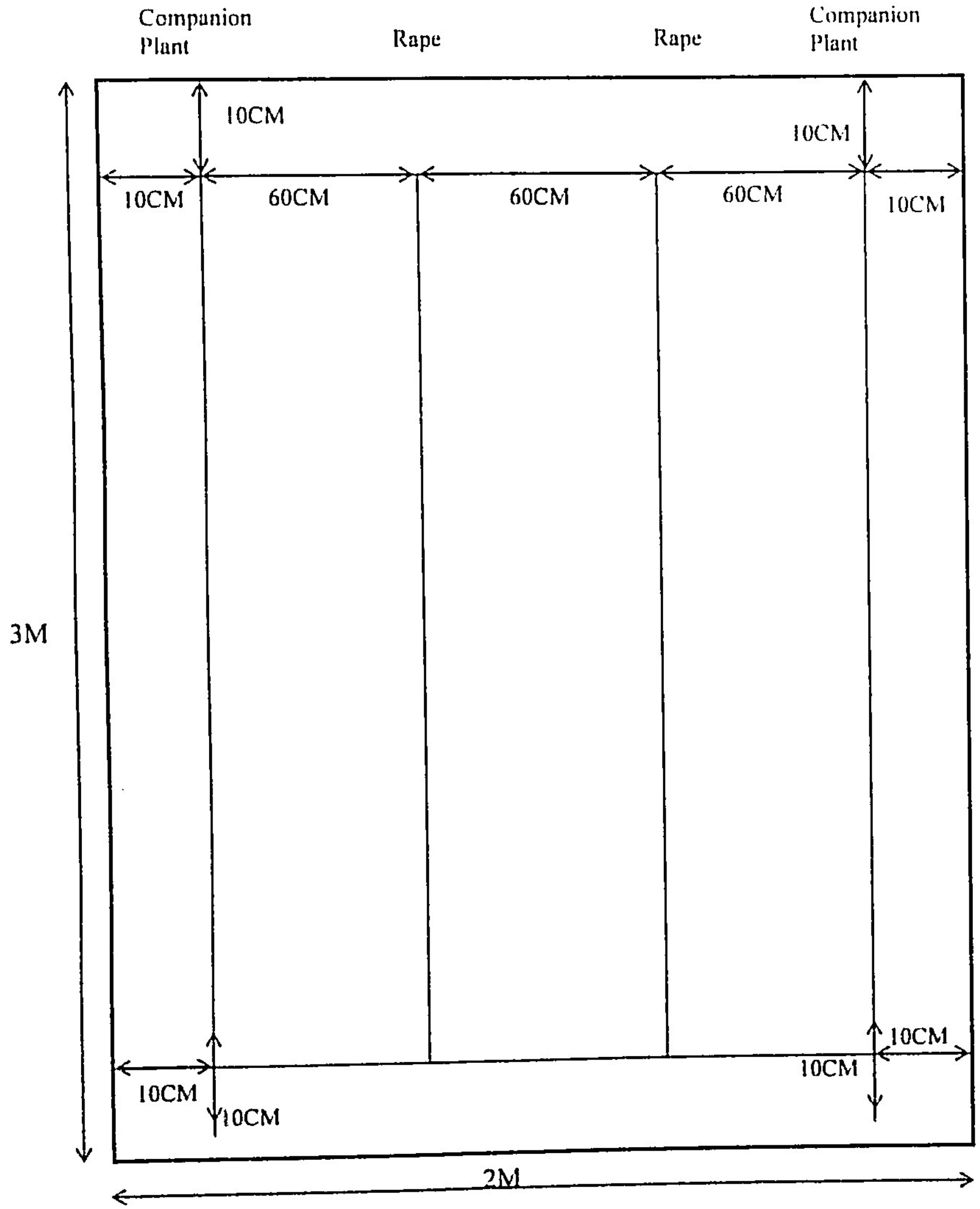
a)

b)

Appendix 4: Plot lay out for the companion planting experiment



Appendix 5: Schematic presentation for spacing between rape and botanicals



Appendix 6: Aphid infestation and damage on untreated rape plant

Appendix 7: Vigorous growth of aphid-free rape treated with imidacloprid

Appendix 8: Growth of untreated rape plants

Appendix 9: Rape intercropped with basil showing closed canopy

Appendix 10: Rape intercropped with mint

Appendix 11: Rape intercropped with marigold showing closed canopy

Appendix 12: Rape intercropped with garlic

Appendix 13: ANOVA Tables

a) Effect of spraying botanical extracts and soap solutions on mortality of cabbage aphid on rape plants under net shade conditions

Source	DF	Sum of squares	Mean squares	F value	Prob
Season	1	4746.094	4746.094	663.8538	0.0000
Treatments	11	90082.365	8189.306	1145.4687	0.0000
Interaction	11	4007.281	364.298	50.9558	0.0000
Error	72	514.750	7.149		
Total	95	99350.490			

b) Effect treatment on cabbage aphid population on rape for a period of 8 weeks

Source	DF	Sum of squares	Mean squares	F value	Prob
Replication	3	2146.174	715.391	5.1497	0.0018
Treatments	5	74158.794	14831.759	106.7651	0.0000
Sampling effect	15	67723.414	4514.894	32.5001	0.0000
Interaction	75	39857.414	531.432	3.8255	0.0000
Error	285	39592.076	138.920		
Total	383	223477.872			

c) Effect of treatment on rape leaf yield

Source	DF	Sum of squares	Mean square	F Value	Prob
Sampling time	3	1.727	0.576	33.2400	0.0000
Treatments	5	5.506	1.101	63.5677	0.0000
Interaction	15	6.391	0.426	24.5962	0.0000
Error	72	1.098	0.017		
Total	95	14.871			

d) Effect of treatment on rape marketable leaf yield

Source	DF	Sum of squares	Mean square	F Value	Prob
Sampling time	3	0.557	0.186	15.8602	0.0000
Treatments	5	67.562	13.512	1154.4321	0.0000
Interaction	15	1.815	0.121	10.3386	0.0000
Error	72	0.843	0.012		
Total	95	70.777			