Evaluation of Selected Bio-rational and Synthetic Insecticides against Cabbage Aphid (*Brevicoryne brassicae*) (Homoptera: Aphididae) on Cabbage in the Central Rift Valley of Ethiopia

MSc. THESIS

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HAWASSA UNIVERSITY
COLLEGE OF AGRICULTURE

Hawassa, Ethiopia
December, 2021

Evaluation of Selected Bio-rational and Synthetic Insecticides against Cabbage Aphid (*Brevicoryne brassicae*) (Homoptera: Aphididae) on Cabbage in the Central Rift Valley of Ethiopia

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A THESIS SUBMITTED TO SCHOOL OF PLANT AND HORTICULTURAL SCIENCES, HAWASSA UNIVERSITY, COLLEGE OF AGRICULTURE, SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF THE MASTER OF SCIENCE IN PLANT SCIENCE (SPECIALIZATION: CROP PROTECTION)

HAWASSA, ETHIOPIA

December, 2021

APPROVAL SHEET - 1

This is to certify that the thesis entitled "**Evaluation of Selected Bio-rational and Synthetic Insecticides against Cabbage Aphid (***Brevicoryne brassicae***) (Homoptera: Aphididae) on Cabbage in the Central rift valley of Ethiopia**", Submitted in partial fulfillment for the degree of Master of Science in Agriculture (specialization: **Crop Protection)**, the Graduate Program of the Department of Plant and Horticultural Sciences, and has been carried out by **Etenesh Adnew Aloto** under my/our supervision. Therefore I recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the department.

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ACKNOWLEDGEMENTS

First of all, I greatly thank the Almighty God, creator, and master of the universe, for giving me endurance and power for the completion of this study. I would also like to express my special gratitude to my research advisors Dr. Ferdu Azerefegne and Mr. Beniam Tilahu (MSc, Assistant Professor) much of the success of this work is attributable to the invaluable suggestions, useful advice, thoroughness, painstaking supervision, very creative guidance and words of encouragement I have received from them. I wish to seize this opportunity to express my profound gratitude to them.

I also express my sincere thanks and deep gratitude to Hawassa University field technicians Tekle Tadesse, Kassa Gadebo, and Dawit Kassa for their cooperation and assistance during the fieldwork. I am also thankful to farmers of the Oromia Region, especially Batu for the facilitation of material and moral help during the fieldwork.

I want to extend a multitude of thanks to my classmates for their encouragement morally. I am deeply thankful to my beloved family: my father Adnew Aloto, my lovely mother Bogalech Tesiso, my sister Bizunesh Adnew and my Brother Adimasu Adnew for their commitment in bringing me up and strong support through my life and the academic profession. I would like thanks to my dear husband Teketel W/amanuel and my children.

I would like to acknowledge the Kembata Tembaro Zone Administration for the opportunity as well as financing the study. I am also thankful to the vegetable IPM project for the financial support during my research work without which this work would have not been accomplished.

I have also heartful gratitude and appreciation to Hawassa University for providing me with quality education with the help of practical training and other facilities.

Finally, I am also indebted to the many of those whose names are not mentioned here for encouraging me and supporting me both materially and morally during my study period.

DEDICATION

This thesis is dedicated to my beloved children Bekalu, Wima, and Blen Teketel for their endless love inspires my soul, and my beloved parents; my mother Bogalech Tesiso and my father Adnew Aloto.

STATEMENT OF THE AUTHOR

First, I declare that this Thesis is my own work and that all sources of materials used for this Thesis have been duly acknowledged. This Thesis has been submitted in partial fulfillment of the requirements for MSc degree at the Hawassa University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that the thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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LISR OF ACRONOMYS AND ABBREVIATIONS

ANOVA	Analysis of Variance
Bt	*Bacillus thuringiensis*
Cm	Cent meter
CRV	Central Rift Valley
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAT	Days after transplanting
DF	Degree of freedom
EC	Emulsifiable concentrates
EPF	Entomopathogenic fungi
IPM	Integrated pest management
Kg/ha	Kilogram per hectare
LSD	List Significant difference
M	Meter
m.a.s.l	Meter above sea level
RCBD	Randomized Completely Block Design
SAS	Statistical Analysis Software

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Evaluation of Selected Bio-Rational and Synthetic Insecticides against Cabbage Aphid (*Brevicoryne Brassicae*) (Homoptera: Aphididae) on Cabbage in the Centeral Rift Valley of Ethiopia

Etenesh Adnew (BSc)

ABSTRACT

Cabbage (Brassica oleracea L. var. capita) is one of the most popular food crops and grows well in many parts of Ethiopia. One of the constraints for the production and use of head cabbage is cabbage aphid (Brevicoryne brassicae (L.)) which damages cabbage from seedling to final growth (head formation) stage. This study aimed to evaluate the efficacy of selected bio-rationales and to investigate the use of effective bio-rationales in rotation with synthetic insecticides against cabbage aphids under field conditions. Field experiments were conducted in two locations at Batu, Eastern Shewa of Oromia Regional state, and Hawassa, Sidama Regional state during the dry season of 2019/2020. Two separate experiments were laid out in a randomized complete block design (RCBD) with four replications. The first experiment was an efficacy test of bio-rational insecticides (mixture of natural plant extracts and phytoenzyme, Spinosad, Millettia ferruginea, Nimbecidine, Sophora flavescens plant extract 25% + emamectin benzoate 1% SL, dimethoate 40% EC (as a standard check), and untreated plots). The second experiment was an efficacy test of selected bio-rational and synthetic insecticides in rotation (Nimbecidine + dimethoate 40% EC, Sophora flavescens plant extract 25% + emamectin benzoate 1% SL+ dimethoate 40% EC, mixture of natural plant extracts and phytoenzyme + dimethoate 40% EC, Spinosad+ dimethoate 40% EC, Milletia ferruginea+ dimethoate 40% EC, dimethoate 40% EC (as a standard check) and untreated plots). The results showed that all bio-rational insecticides reduced aphid population when compared with the untreated plots. Spinosad, Nimbecidine, and a mixture of natural plant extracts and phytoenzyme effectively controlled aphids on cabbage and were comparable to the standard check (dimethoate 40% EC) and gave higher yield. The maximum total yield of head cabbage was obtained from dimethoate 40% EC treated plots, 57.6 tons/ha and 58.4 tons/ha, followed by Spinosad 55.4 and 56.4 tons/ ha at Hawassa and Batu, respectively; Nimbecidine 51.4 tons/ ha at Hawassa which were not significantly (P<0.05) different from dimethoate 40% EC treatment. In rotation applications of Spinosad, Nimbecidine, and a mixture of natural plant extracts and phytoenzyme with dimethoate 40% EC effectively controlled aphids on cabbage and were comparable with the sole application of standard insecticide (dimethoate 40% EC). The highest total yield of head cabbage was obtained from dimethoate 40% EC treated plots, 60.6 tons/ ha at Hawassa and 61.2 tons/ ha at Batu, and was not significantly different from Spinosad + dimethoate 40% EC treatment in both locations and Nimbecidine+ dimethoate 40% EC at Hawassa. The lowest yield (12.8, 12.4 ton/ha) was obtained from the untreated plots. Thus, Spinosad, Nimbecidine, and mixture of natural plant extracts and phytoenzyme as a sole application or Spinosad, Nimbecidine, and mixture of natural plant extracts, and phytoenzyme in rotation with dimethoate 40% EC can be used to control cabbage aphids on cabbage.

Key words: Bio-rational, cabbage aphid, efficacy, rotation, synthetic insecticides;

1. INTRODUCTION

1.1. Background and Justification

Cabbage (*Brassica oleracea* L. var. capitata) is a versatile vegetable crop that belongs to the Brassicaceae family (Richardson, 2016). It is a widely grown vegetable throughout the world. It also remains a very vital crop for farmers and gardeners enabling the small-scale farmer to be financially viable mainly in Africa and Asia. Cabbage is one of the most popular food crops (Embaby and Lotfy, 2015). It is grown for domestic uses as well as, for the market as one source of business (Munthali and Tshegofatso, 2014). It is also one of the major Ethiopian economically important vegetables (Emana *et al.*, 2015). The production level of head cabbage in Ethiopia is about 245,650.47 quintals in an area of 3,629.92 hectares in the main rainy season (Meher) (CSA, 2020).

Cabbage is known for its nutritional importance and it is rich in minerals and vitamins like A, B1, B2, and C. Being an appetizer, it aids digestion thereby helps to prevent constipation and also protects against cancers (Kibar *et al.*, 2014). Cabbage is also an important vegetable that reduces human health problems and is used to make cabbage-based conventional medicines for heart disease, stroke, alleviate rheumatism and skin problems (Rokayya *et al.*, 2013).

Ethiopia has favorable agro-climatic conditions for the production of head cabbage. However, cabbage yield and quality are influenced by several factors, among these factors insect pests and poor agronomic practices are the main yield and quality limiting factors during cabbage production. Among insect pests cabbage aphid are very serious in cabbage-growing areas of Ethiopia, especially in the dry season. Cabbage aphid *Brevicoryne brassicae* inflict damage on brassica crops in Ethiopia (Shiberu and Mulugeta, 2016). Cabbage aphid causes significant yield losses in many crops in the family Brassicaceae, which includes the mustards and crucifers (Opfer and McGrath, 2013). Infested plants retard growing and flowers fall, not forming fruits. Yellow spots are observed on leaves of food cabbage; these leaves twist and dry up. Plants produce small heads much later. Sticky fecal masses (honeydew) of aphid pollute the leaves. This can reduce cabbage yield marketable value and nutritional contents (Wubie *et al.*, 2014). Aphid cause severe plant infestation that gives the reduction of plant growth, number of side branches, and the oil content (Embaby and Lotfy, 2015). Yield loss studies at Melkasa Agricultural Research Center (MACR) of the Ethiopian Institute of Agricultural Research (EIAR) showed that losses vary between 36.1-91.2% and complete crop failures are common in seasons of heavy infestations (Gashawbeza *et al.*, 2009).In addition to the impact of feeding, aphids also transmit 50% of all insect-borne plant viruses (Gebregziabher, 2017). Aphids also secrete a sticky substance called honeydew, which encourages the growth of saprophytic fungi like *Cladosporium* spp and *Penicillium* spp. which appear as sooty molds blackening the leaf and limiting the leaf area available for photosynthesis (Williams and Dixon, 2007).

Controlling cabbage aphids is not an easy practice although synthetic chemicals are available for use. Effective pest control is no longer a matter of the heavy application of limited insecticides because continuous use of chemicals promotes the development of pesticide resistance in the target pests, pest resurgence, and emergence of secondary pests, affects non-target insects pests' species, affects the environment, and human health (Shiberu and Mulugeta, 2016). Therefore, there is a need for alternative chemicals which cause less harm to the environment and human health such as bio-rational insecticides. Bio-rational insecticides are synthetic or natural substances that are more effective to control insect pests and are low toxicity to non-target organisms and the environment (Hara, 2000). Currently, the major pest management strategy followed by vegetable producers in Ethiopia is the frequent application of synthetic insecticides (Belay *et al.*, 2017). Moreover the efficacy of various bio-rational insecticides' in managing cabbage aphid is not adquatly tested in the Ethiopia. Therefore, this experiment was designed to evaluate the selected bio-rational and synthetic insecticides against cabbage aphid management.

1.2. Objectives of the study

1.21. General objective

- ☞ To investigate the efficacy of selected bio-rational insecticides and develop integrated use of bio-rational with synthetic insecticides for sustainable management of cabbage aphid

1.2.2. Specific objectives

- ☞ To evaluate the efficacy of selected bio-rational insecticides against cabbage aphids
- ☞ To test the efficacy of selected bio-rationals and synthetic insecticides in rotation against cabbage aphids

2. LITERATURE REVIEW

2.1.Economic Importance of Head Cabbage

The world's annual production of cabbage is around 70,644,191 tons with an average yield of about 29.23 tons/ha (Kidane, 2016). The five cabbage producers of African countries are Kenya, Egypt, Ethiopia, Nigeria, and South Africa and these five countries have maintained the dominance of the sector throughout this period. Area production and yield of cabbage in Ethiopia in 2019/2020 were 3629.92 hectares, 245650.47 quintals, and 67.67 qt/ha, respectively. In Oromia, a regional state the area covered by head cabbage in the year 2019/2020 was 2331.62 ha while the production was 158717.89 qt and the yield is 68.07 qt/ha. Area production and yield of cabbage in Southern Nations Nationalities peoples Region were 555.47 hectares, 31,925.17 quintals, and 57.47 qt/ha (CSA, 2020)

Cabbage is cultivated for its head, which consists of water (92.8%), protein (1.4 mg), calcium (55.0 mg), and iron (0.8 mg) in 100g cabbage; the leaves are eaten raw in salads or cooked. Head of cabbage, which can grow from 0.5 to 4 kilograms, is rich in vitamins and minerals, has almost no fat, and is very rich in fiber which makes it very healthy to eat. Cabbage health benefits include reducing the risk of cancer, improving brain and nervous system health, promoting bone health, maintaining blood pressure, detoxifying the body, promoting bowel regularity, regulating sugar levels, and promoting weight loss. Other benefits include improving the health of hair, skin, and nails, helping prevent or heal acne, healing stomach ulcers, helping care for the heart, promoting healthy pregnancy, and boosting immunity (Brandi, 2019).

2.2. Constraints of Head Cabbage Production in Ethiopia

Cabbage production suffers from many constraints, including abiotic and biotic factors. Abiotic factors such as extreme temperatures, soil salinity, relative humidity, and moisture content limits yield and quality of crop (Solomon *et al.*, 2018). The temperature may limit the use of the cabbage crop, in part because cabbage growth is particularly affected by both high and low temperatures. Temperature above 43.2 °C, growth is arrested in most of the cultivars. Cabbage plants that are exposed to temperatures of 10-13 °C for prolonged periods will produce premature seed stalks instead of heads (Solomon *et al.*, 2018). It does not grow well in highly acidic soil and below 4.5 is affect the growth of the cabbage crop.

Biotic factors such as diseases, insect pests, and weeds cause yield losses in cabbage production. Diseases like Black Rot (*Xanthomonas campestris* pv. campestris); this bacterial disease is common in areas having a warm and wet climate. Plants can be infected during any growth stage and the symptoms resemble nutritional deficiencies, and soft rot (*Erwinia carotovora*) (Bok *et al.*, 2006). Insect pest, diamondback moth (*Plutella xylostella* L. Lepidoptera: Plutellidae), cabbage aphid (*Brevicoryne brassicae* L. Hemiptera: Aphididae), flea beetles (*Phylloterta spp*), and cabbage leaf miner (*Chromato myiahorticola* Goureau) (Diptera: Agromyzidae) are of economic importance (Gashawbeza *et al.*, 2009). The diamondback moth is the dominant and most destructive insect pest of crucifer crops worldwide. Yield loss studies at Melkasa Agricultural Research Center (MACR) of the Ethiopian Institute of Agricultural Research (EIAR) showed that losses vary between 36.1-91.2% and complete crop failures are common in seasons of heavy infestations (Gashawbeza *et al.*, 2009). According to Pal and Singh (2012), the cabbage aphid may decrease 34-62% of cabbage yield. Cabbage aphids are very serious in cabbage growing areas of Ethiopia especially in the dry season, and inflict damage on brassica crops in Ethiopia (Shiberu and Mulugeta, 2016). According to Opfer and McGrath (2013), cabbage aphid causes significant yield losses in many crops in the family Brassicaceae, which includes the mustards and crucifers. According to Khan *et al.* (2015), cabbage aphid causes 35-75 percent yield losses.

2.3. Cabbage Aphid

The cabbage aphid belongs to the genus Brevicoryne. The name is derived from the Latin words "brevi" and "coryne" and which loosely translates as "small pipes". In aphids, there are two small pipes called cornicles or siphunculi (tailpipe-like appendages) at the posterior end. The cornicles of the cabbage aphid are relatively shorter than those of other aphids except the turnip aphid *Lipaphis erysimi* (Kaltenbach). These short cornicles and the waxy coating found on cabbage aphids help differentiate cabbage aphids from other aphids that may attack the same host plant (Carter and Sorensen, 2013; Opfer and McGrath, 2013). The cabbage aphid is 2.0 to 2.5 mm long and covered with a grayish waxy covering, but the turnip aphid is 1.6 to 2.2 mm long and has no such covering (Carter and Sorensen, 2013).

2.3.1. Distribution

The cabbage aphid is scattered in many parts of the world (Khanjani, 2006). It is indigenous to Europe, but now has a universal distribution (Kessing and Mau, 1991). According to Carter and Sorensen (2013) study, the cabbage aphid is widely spread throughout the United States and is more of a pest in the southern states. It is a cosmopolitan species available in different agro-climatic conditions of the world where brassica crops are grown, particularly cabbage. The cabbage aphid is native to Europe, but now has a worldwide distribution (Kessing and Mau, 1991). Headed cabbage had become one of the most important vegetables in 16th century in

Europe. From then onwards headed cabbage was introduced worldwide. In tropical and subtropical areas commercial cultivation is still mostly restricted to the cooler climates of the highlands or the mild cool seasons at higher latitudes. In Africa, head cabbage is especially common in East Africa and Egypt (Nieuwhof, 1969).

2.3.2. Economic importance

Cabbage aphids are important pests of members of the Cruciferae including, cabbage, collards, cauliflower, swede, mustard, Brussel sprouts, and radish. The cabbage aphid is a destructive pest in all cabbage growing areas (Bhatia and Verma, 1994; Dattu and Dattu, 1995) causing severe loss of yield in cruciferous crops that reduce their marketability (Liu *et al.*, 1994; Costello and Altieri, 1995). Also, aphids feeding may lead to unmarketable head, stunted growth, and eventually death of the plant (Griffin and Williamson, 2012). The indirect damage includes secretion of honeydew, contamination of harvested produce, and the transmission of viral diseases (Liu *et al.*, 1994). The honeydew produced by cabbage aphids tends to stimulate the growth of a black sooty mold fungus which contaminates the crop and reduces its market value (Costello and Altieri, 1995). With even low population density, aphids have an economic impact on the growth and yield of the crop (Kessing and Mau, 1991). Cabbage aphid (*B. brassicae*) is one of the important pests (Jankowska and Wiech, 2004) and their damage potential affects the quality and market value of the cabbage. According to Rauf *et al.* (2005), 70% of farmers growing cabbage crops spend 25-30% of the total production input cost to purchase pesticides. In India aphids alone attribute 30-70% losses in rapeseed yield in different agro-climatic conditions with an average loss of 52.2%. Under favorable circumstances, aphid populations increase very rapidly by making dense colonies on all parts of plants. The economic impact of aphid damage can be from 80% yield losses to complete crop failure if the attack comes at the seedling stage

(Shoaib, 2003). In Pakistan, cabbage aphid and mustard aphid are important pests of Brassica. Cabbage aphid causes 35-75% yield losses and 6% losses in oil contents (Rehman and Yousaf, 1987).

Damage caused by aphids through feeding results in poor plant growth and indirect damage can occur from honeydew and mold growth or the transmission of viral plant pathogens (Satar *et al.*, 2005). Continued feeding by aphids causes yellowing, wilting, and stunting of plants (Opfer and McGrath, 2013). Severely infected plants become covered with a mass of small sticky aphids (due to honeydew secretions), which can eventually lead to leaf death and decay (Grifn and Williamson, 2012). Cabbage aphids feed on the underside of the leaves and the center of the cabbage head (Hines and Hutchison, 2013).

Aphids cause direct damage by causing chlorosis and leaf curling on the leaves while disrupting the normal plant growth and development (Colette *et al.*, 2008). In addition to the impact of feeding, aphids damage through the transmission of viral diseases (Jahan *et al.*, 2013). Aphids cause major losses to broccoli by reducing yield, with real damage being contamination of harvested heads of broccoli (Natwick, 2009; Opfer and McGrath, 2013). In Oregon, contamination of some broccoli heads may lead to the rejection of the entire harvest by quality assurance programs managed by broccoli processors (Opfer and McGrath, 2013).

2.3.3. Biology

The cabbage aphid are grayish-green with a waxy covering that gives them a grayish-white appearance (Hines and Hutchison, 2013, Natwick, 2009, Opfer and McGrath, 2013). *B. brassicae* can produce overwintering eggs that hatch in February to March but often it is the parthenogenic nymphs and adults that overwinter (Emden and Harrington, 2007).

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

Eggs are usually produced in temperate climates and overwinter in plant debris near the soil surface (Hines and Hutchison, 2013) whereas in warm climates only females are found in the colony, and live female nymphs are produced directly without egg-laying (Kessing and Mau, 1991). In warm climatic conditions, eggs are usually not produced but rather the female gives birth to live females called nymphs. The nymphs are similar in appearance to the adult but slightly different in terms of their small body size, with less developed caudal and siphunculus. The nymphal period ranges from seven to ten days. Those that form wings develop and migrate to new host plants when the quality of the plant reduces or when the population is large (Hines and Hutchison, 2013; Opfer and McGrath, 2013).

2.3.4. Host range

Major economic hosts include broccoli, cauliflower, and head cabbage. It attacks carrot, celery, Chinese broccoli, Chinese cabbage, daikon, radish, kale, rape, and most other members of the genus Brassica; however, the damage is usually less severe than on cabbage (McGrath and

Opfer, 2013). Cabbage aphid is an especially big problem in broccoli and cabbage production (Opfer and McGrath, 2013). Aphids are ordinary pests of vegetables, annual and perennial flowers, ornamental shrubs, and trees. They frequently are found on cabbage, tomato, and potato. Most aphids only feed on one or two species of plants. However, cabbage aphids can attack a wide range of garden plants as an alternate host. This includes crops like broccoli, cauliflower, kale, and mustard (Elwakil and Mossler, 2013).

2.4. Management of Cabbage Aphid

2.4.1. Cultural control

Cultural control is the use of various agricultural practices to make the habitat less suitable for the reproduction and/or survival of pests. It is a long-established method of pest control. Cultural control aims, therefore, to reduce rather than eradicate pest populations and is typically used in conjunction with other control methods. However, in some instances, cultural practices alone may affect almost complete control of a pest. The agricultural practices used either may have a direct effect on the pest or may act indirectly by stimulating population buildup of a pest's predators or parasites, or by making plants and animals more tolerant of pest attack. An essential prerequisite for effective cultural control is detailed knowledge of a pest's life history so that its most susceptible stages can be determined (Gebregziabher, 2017).

The crop cultivated field should be plowed immediately after harvest, therefore, to prevent the spread of aphids to other crops (Grifn and Williamson, 2012). According (Natwick, 2009) after harvest, plowing under crop remains is important to rid the field and surrounding areas of any alternate host plants like mustards or other cruciferous weeds. Destruction of plant debris at the end of the season can help kill overwintering aphid eggs in temperate climates (Hines and

Hutchison, 2013). Crop rotation with non-host crops is also beneficial (Kessing and Mau, 1991). Choice of cultivar could also reduce aphid populations and damage. For example, the cauliflower cultivar 'Smilla' could be a good choice because it affects adult reproductive parameters (Jahan *et al.*, 2013). Avoid replanting on land where an aphid-infested crop has been recently removed. Plant spacing is not considered as an effective approach for cabbage aphid control in canola (*Brassica napus* L.) crops (Razaq *et al.*, 2012)

2.4.2. Biological control

Biological control relies on the organism to decrease the insect pest population (Van Lenteren, 2012). Biological control occurs in every ecosystem of the world and its contribution to agriculture is enormous (Muneret *et al.*, 2019). Organisms including pathogens, predators, parasitoids, and nematodes are important in effecting biocontrol in the ecosystem. It has been described as the safest and the most economically profitable pest management option (Cock *et al.*, 2010; Messing and Brodeur, 2018). Biological control has been in existence for ages and has coevolved with agriculture (Gurr and You, 2016). Effective biological control often requires a good understanding of the biology of the pest and its natural enemies (Michaud *et al.*, 2008).

2.4.2.1. Predators and parasitoids

Parasites and predators are important for regulating aphid populations. The parasitic wasp *Diaeretiella rapae* (Hymenoptera: Aphidiidae) lays eggs within half-grown nymphs (preferring 2^{nd} to 4^{th} instars over 1st instar nymphs and adults) and mummifies them, forming a light brown, hard shell around the aphid. Although *Diaeretiella rapae* is a very common parasite it is not always effective in controlling aphids (Belaynesh, 2018).

Protecting habitat that will foster the population and survival of natural enemies can help reduce the need for pesticides (Natwick, 2009). Syrphid fly maggots, lady beetle adults and larvae, and lacewing larvae (aphid lions) are common predators of aphids. Seed extract of the Chinaberry tree (*Melia azedarach)* (Baidoo and Adam 2012, Kibrom*et al.* 2012, Mekuaninte *et al.* 2011). Acheampong and Stark (2004) investigated the potential of using reduced rates of the selective aphicide (pymetrozine) and two biological control agents both in the laboratory and in the field to control *Brevicoryne brassicae*. In the laboratory the highest reduction of aphids (98%) was obtained when the low dose of pymetrozine was combined with both biological control agents. In caged field experiments, when pymetrozine was used at half field rate a 99.8% reduction in aphid numbers was obtained. This rate of suppression with pymetrozine was too effective for the potential additive reduction of aphids by biological control agents to be evident.

2.4.2.2. Entomopathogens

Entomopathogenic bacteria

The majority of Entomopathogenic bacterial pathogens of insects occur in the family Bacillaceae, Pseudomonadaceae, Enterobacteriaceae, Streptococcaceae, and Micrococcaceae. Bacillus thuringiensis is arguably the most widely studied and used bacterial entomopathogen (Azizoglu, 2020). This bacterium is the production of parasporal bodies (crystals) containing specific insecticidal endotoxins (Cry proteins) acting by ingestions through a pore-forming mechanism of action detrimental for the insect gut epithelium (Pigott and Ellar, 2007). Different studies evaluate the effects of Bt toxins on both insect pests (Pérez-Guerrero *et al.,* 2012) and non-target species (Marchetti *et al.,* 2012). The mode of action of this new entomopathogenic bacterium is complex and different are the metabolites that have recently been associated with the insecticidal effects (Asolkar *et al.*, 2014).

Entomopathogenic nematode

Entomopathogenic nematodes occur naturally in soil environments and locate their host in response to carbon dioxide and other chemicals (Kaya and Gaugler, 1993). Entomopathogenic nematodes are being produced commercially and used as biological control agents against many soil insect pests and insects (Kaya and Gaugler, 1993; Kaya and Stock, 1997; Boemare, 2002). Entomopathogenic nematodes are soil organisms, which live with bacteria in a symbiotic-mutualistic relationship. Entomopathogenic nematodes have the potential for biological control of insect pests. The symbiotic association of entomopathogenic nematodes with specific bacteria facilitates reproduction (bacteria serve as food) and pathogenicity of the nematodes. Nematodes act as vectors to transport the bacteria into a host within which they can multiply, and the bacteria create conditions necessary for nematode survival and reproduction within the insect cadaver (Dowds and Peters, 2002). It is well known that entomopathogenic nematodes, which are classified into Steinernematidae and Heterorhabditidae families, have great potential as biological control agents in plant protection (Klein, 1990).

Entomopathogenic fungi

Aphids are attacked by many entomopathogens, predators, and parasitoids (Skouras *et al.*, 2015). Many entomopathogenic fungi like *Beauveria bassiana* (Balsamo) Vuillemin, *Metarhizium anisopliae* (Metschnikoff) Sorokin, *Lecanicillium lecanii* (Zimm.) Zare and Gams, have been reported to be effective against aphids (Jouda *et al.*, 2010; Ujjan *et al.*, 2012). Prevalent high humidity favors the development of entomopathogens and this may be the leading cause of insect mortality and avoids the buildup of resistance to insecticides and also conserves its natural enemies. According to Mandi *et al.* (2016), the field efficacy of *B. bassiana* with 54.4% reduction of aphid population of *Myzus persicae* (Sulzer) in cabbage in Mohanpur, West Bengal.

Meena *et al.* (2013) the field efficacy of *B. bassiana*, *V. lecanii*, and *M. anisopliae* at the rate of 5g/l showed 78, 75, and 74% reduction of mustard aphid, *Lipaphis erysimi* population over control in Bharatpur, Rajasthan.

2.4.3. Host plant resistance

This is a technology that represents an attractive control tool to farmers, particularly those in the urban areas in Ghana (Horna *et al.*, 2007). Plant species, on which insect pest development is delayed, increase the vulnerability of pests to natural enemies and their rates of parasitism (Benrey and Deno, 1997). Plants that are more vulnerable to pests are called susceptible plants and those which can strongly tolerate attacks are considered resistant. There are three general types of mechanisms for resistance i.e. antibiosis, antixenosis, and tolerance. Antibiosis is defined as the adverse effect that a plant may have on the pest because of chemicals or structures the plant possesses. Antixenosis resistance involves behavioral factors that cause an insect not to choose the plant for feeding or laying its eggs, while tolerance is a characteristic of some plants that enable them to withstand or recover from insect or disease damage (Van Emden, 2007).

The resistance is chemically based and elicits antibiosis in the larvae, causing levels of mortality (Eigenbrode and Shelton, 1990). In Europe and India, rape and brussel sprouts varieties were identified to be resistant to cabbage aphid (Russel, 1978; Pakhraj *et al.*, 2005). Some cultivars of crucifera have also shown to be resistant to cabbage aphid infestation than others (Singh and Ellis, 1993; Ellis*et al.*, 1998)

2.2.4. Botanical insecticides

Many African countries are rich in plant products that are traditionally used by the rural inhabitants for medicinal purposes and in some instances as preparations for insect control

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

An eco-friendly alternative to chemical pesticides is the use of bio-pesticides, which encompass a broad array of microbial pesticides, bio-chemicals derived from micro-organisms, and other natural sources, which confer protection against pest damage. The potential benefits to agriculture and public health programs through the use of bio-pesticides are considerable. India has a vast potential for bio-pesticides. Bio-pesticides, being target pest-specific, are presumed to be relatively safe to non-target organisms including human beings. All the chemical and bio-rational insecticides tested against major insect pests of cabbage were found effective over untreated control in reducing the aphid and larval population of the diamondback moth. There are broadly in conformity with the findings of (Heidi and Eileen, 2008; Sharma and Mehta, 2009) as having documented neem oil and Eupatorium extract as effective treatments against cabbage aphid under laboratory conditions. Similarly, Patil and Patel, 2014 have found neem oil at the rate of 0.5% in a little higher concentration effective against *Aphis gossypii* in isabgol crop under field conditions.

2.4.5. Synthetic insecticides

Application of synthetic chemicals for plant protection plays an important role in addition to other agronomic managements for maximum crop production (Iqbal et al., 2011). The chemical control, use is made of various non-systemic insecticides like Malathion, Thiodan, Diazinon, etc., and also with systemic insecticides like Rogor, Metacid, Metasystox, etc. The spray of these chemicals would require a long period of safety but may affect the bees for pollination. Thiodan may be a comparatively safer chemical for use in seed crops also. Many insecticides are effective against aphids. Care must be taken that sprays thoroughly wet the plants, because of the waxy nature of the pest and crop. To achieve maximum control with minimum efforts, proper surfactant proportions in combination with well-adjusted spray equipment are important (Kessing and Mau, 1991). Aphids have been managed using insecticidal soaps (e.g. Safer Soap). Insecticides belong to different groups like organochlorines, organophosphates and pyrethroids have been used to control aphids on Brassicas (Dewar, 2007). Natural and synthetic chemicals are traditionally used to kill pests and have been used as major methods of pest control for about 90 years (Gillott, 2005). Based on mean percent reduction of aphid, *L. erysimi* population, and imidacloprid (87.72) was found to be most effective reducing aphid population on cabbage crop followed by standard check endosulfan (84.74) and malathion (83.47) resulted in percent reduction, respectively (Jugal, 2011).

The use of insecticide seed treatments can delay aphid colonization and reduce early Infestation, aphid feeding, and the spread of viruses. Cabbage aphids often select varieties with more waxy leaves and are hidden between leaves, so limiting the efficiency of chemical control (Ellis *et al.*, 1996). Therefore, the use of systemic insecticides is inevitable (Schroder and Dombleton, 2001; Umeda and Mcneil, 2000).

Some pesticides are harmful to pollinators' such as wild bees, certain wasps, honeybees, and other insects causing direct losses of the insect populations and indirect losses of crop yield because of the lack of adequate pollination. In addition, the most obvious effects of pesticides are direct poisoning of aquatic organisms like fish and wildlife. In many cases, however, the indirect effects of pesticides, such as causing dissolved oxygen depletion. They also kill birds in several ways, including direct ingestion of granules, baits, treated seeds, and direct exposure to sprays. Indirect bird kills may result from consumption of treated crops, contaminated water, or feeding on contaminated prey. Inert ingredients in pesticide formulations may also be capable of causing phytotoxicity (Fishel, 2005). Many chemical pesticides have a broad spectrum of action and therefore kill beneficial insects that serve in the recycling of organic materials that increase soil fertility. Furthermore, some of the insects killed are natural enemies of the target pest, which are often more sensitive to the pesticide than the pest itself (Van Driesche and Bellows, 1996; Schepers, 1989).

2.4.6. Bio-rational insecticides

There are many alternative control options to manage insect pests by use of biocontrol agents, microbials, and botanicals (Lowery and Isman, 1994; Milner, 1997; Singh *et al.*, 2007; Bugg *et al.*, 2008). These bio-rational or low-risk pesticides are being used to replace conventional ones. Bio-rational insecticides are synthetic or natural substances that are more effective to control insect pests with having low toxicity to non-target organisms and the environment (Hara, 2000). These are being developed by the agrochemical companies and due to the reasons of being more selective, these fit well in Integrated Pest Management (IPM) programs (Casida and Quistad, 1998; Horowitz *et al.*, 2004). According to Adhikari (2011), Nimbecidine was effective in reducing the cabbage aphid population; it showed an average control of up to 48.22% in different sprays. Rawat (2006) stated that the population reduction over control of *Verticillium lecanii* to mustard aphid was 40.80-51.60%.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment were conducted at Hawassa and Batu areas in the Central Rift Valley (CRV) of Ethiopia. The experiment sites were about 273 km (Hawassa) and 160 km (Batu) South of Addis Ababa, East Shewa Zone of Oromia Regional State and Sidama Regional State.Hawassa is located $7^0$3'N $38^0$28'E / 7.050^0N 38.467^0E and has an elevation between 1,708 and 1920 meters above sea level. The area receives a mean annual rainfall of 953 mm and has a mean temperature 20.3^0c (Hawassa Metrological Agency, 2019). Batu is located 7° 9'N latitude and 38° 7'E longitude at, an altitude of 1650 m.a.s.l. and with bimodal unevenly distributed average annual rainfall of 760.9 mm per annum. The long-term mean temperature ranged 12.6 - 27^oC (ATARC, 1998).

3.2. Planting Material

The cabbage variety, Copenhagen Market, was used for the study. It is an early head forming type with compact, round and large head (Rail and Yadav, 2005).

3.3. Experimental Procedure and Field Management

Nursery management: The cabbage nursery bed was prepared on an area of 9 m^2 during the first week of November /2019 and seeds were sown through line spacing at 0.5cm depth. Seedlings were managed in the nursery for 40 days. All nursery management practices, such as mulching, watering, fertilizer application, and weeding were executed to raise vigorous and healthy seedlings.

Transplanting: The seedlings with 6 to 7 leaves were transplanted during the second weeks of December 2019. One day before transplanting, the nursery beds were irrigated to ease the uprooting of the seedlings. During transplanting healthy, vigorous, and uniform seedlings were transplanted.

Field management and procedures: The field was plowed using oxen and harrowed manually to bring the soil to a fine tilth. The seedlings were transplanted to well prepared and irrigated experimental field. Irrigation was applied for the first two weeks after transplanting at four days interval. Then after the experimental plots were irrigated every six days using a furrow irrigation system (Lemma and Shimeles, 2003). Fertilizer di-ammonium phosphate (DAP) was applied during transplanting at the rate of 200 kg/ha (18% N: 46% P_2O_5). Urea was applied at the rate of 100kg/ha (46% N) in split applications at transplanting and a month after transplanting (EARO, 2004). Cultivation, weeding and all other agronomic practices, except insecticides application, were followed for all plots uniformly.

3.3.1. Experiment one: Efficacy of selected bio-rational insecticides against cabbage aphids

The experiment was conducted in the dry season where there was a high level of aphid population. The experiment was set in a randomized complete block design (RCBD) with four replications. The plot size was 6.25m^2 (2.5m x 2.55m) and five rows per plot with a of spacing 0.5 m between rows, 0.5 m between plants. Three central rows were harvested for the experiment. The experiment had seven treatments, i.e., a mixture of natural plant extracts and phytoenzyme, spinosad, *Milletia ferrugenea*, nimbecidine, *Sophora flavescens* plant extract 25% + emamectin benzoate 1% SL, synthetic insecticide Dimethoate 40% EC as a standard check, and untreated plots (Table 1). The insecticides were applied using a manual knapsack sprayer of 15 liters capacity. The experiments were scouted every week for the signs and symptoms of aphids' damage and occurrence till reach the economic threshold level. Before one day each spray the number of aphids was counted from five randomly selected plants from the middle rows of each plot with counted the aid of 10x magnifying hand lens and insecticides were applied when the cabbage aphids population reached the economic threshold level. The experimental plots were sprayed three times within fifteen days interval. The first spray was started (28 days at Batu and 30 days at Hawassa) after transplanting. Three days after each insecticide spray, the number of aphids per plant in each plot was counted using the sampling procedure described above.

3.3.1.1. Methods of Milletia seed extraction

Seeds of *M. ferrugenea* were collected from mature trees in Hawassa. Milletia seeds were dried in a well-ventilated area under shade and then grounded to a fine powder. The powdered seed material was soaked in distilled water at 50g/L and left 24hrs as described by Keshav and Singh (2013). The mixture was filtered with cheesecloth and made ready for spraying.

Table 1. List of biorational insecticides used for the experiment

Trt No	Trade name	Common name	Rate of application	Spray volume	Formulation
1	Gomite	Mixture of natural plant extracts and phytoenzyme	1 L/ha	300L/ha	EC
2	Tracer480SC	Spinosad	0.15 L/ha	200L/ha	SC
3	*M. ferruginea*	Birbira	50g/L	300L/ha	SP
4	Azadirachitin 0.03%	Nimbecidine	3L/ha	600L/ha	EC
5	Aketchi 260SL	*S. flavescens* plant extract 25% + emamectin benzoate 1% SL	0.5L/ha	300L/ha	SL
6	Sarikas	Dimethoate 40%EC	1.2 L/ha	600L/ha	EC
7	Untreated				

3.3.2. Experiment two: Efficacy of selected bio-rational and synthetic insecticide in rotation against cabbage aphid

The experiments were arranged in a randomized complete block design (RCBD) with four replications. The plot size was $6.25m^2$ (2.5m x 2.5m) and five rows per plot with a spacing of 0.5 m between rows and 0.5 m between plants with the middle three rows were harvested for the experiment. The experiment had seven treatments i.e., Nimbecidine + dimethoate 40% EC, *S. flavescens* plant extract 25% + Emamectin benzoate 1% SL + dimethoate 40% EC, Gomite + dimethoate 40% EC, Spinosad + dimethoate 40% EC, *M. ferrugenea* + dimethoate 40% EC and dimethoate 40% EC including untreated plots(Table 2). One day before each spray the number of aphids was counted from five randomly selected plants from the middle rows of each plot with counted the aid of 10x magnifying hand lens and insecticides were applied when the cabbage aphids population reached the economic threshold level.

The experimental plots were sprayed three times at fifteen days intervals using manual knapsack spray. In the bio-rational and synthetic insecticides applied in rotation treatments; the first and third sprays were bio-rationals and the second applications were synthetic insecticides (Table 2). The first spray was started (28 days at Batu and 30 days at Hawassa) after transplanting. Three days after each insecticide spray, the number of aphids per plant in each plot was counted using the sampling procedure described above.

Table 2. Experimental treatments and spray sequence

Trt. No	Sequence of spray 1st spray	2nd spray	3rd spray
1	Nimbecidine	Dimethoate 40%EC	Nimbecidine
2	*S. flavescens* plant extract 25% +Emamectin benzoate 1% SL	Dimethoate 40%EC	*S. flavescens* plant extract 25% +Emamectin benzoate 1% SL
3	Mixture of natural plant extracts and phytoenzyme	Dimethoate 40%EC	Mixture of natural plant extracts and phytoenzyme
4	Spinosad	Dimethoate 40%EC	Spinosad
5	*M. feruginea*	Dimethoate 40%EC	*M. feruginea*
6	Dimethoate 40%EC	Dimethoate 40%EC	Dimethoate 40%EC
7	Untreated		

Nimbecidine was sprayed with a rate of 3L/ha diluted in 600L/ha of water, a mixture of natural plant extracts and phytoenzyme in 1L/ha diluted in 300L/ha of water, 50g/L with 5% aqueous Milletia seed powder suspension 300L/ha, Spinosad in 0.15l/ha diluted in 200L/ha of water, *S. flavescens* plant extract 25% + Emamectin benzoate 1% SL in 0.5L/ha diluted in 300L/ha of water, dimethoate 40% EC in 1.2L/ha diluted in 600L/ha of water.

3.4. Data on Yield Parameters

Head diameter (cm): To measure head diameter five randomly selected heads in each plot were cut vertically at their middle position with a sharp knife. The diameters of the heads are then measured with a meter scale horizontally from one side to another side of the selected heads and mean values were recorded.

Head yield (ton/ha): The head yield obtained from the net plot area of each plot was measured in kilogram and expressed as a ton per hectare.

Marketable and unmarketable yield (ton/ha): Heads that were free from any damages and decay as well as those which haven't loose and open heads were considered as marketable. Heads that fulfilled these characteristics were harvested from the net plot area and expressed as tone per hectare and used for further analysis. Those heads which did not fulfill the above criterion including the wrapper leaves were considered as unmarketable and expressed as tone per hectare. The total yield was then obtained by adding the marketable and unmarketable yields.

3.4.1. Partial Budget Analysis

Cost of treatments (ETB/ha): The price of the insecticides and application costs were recorded.

Gross returns (ETB/ha): The head yield was converted into gross return in birr based on the prevailing market prices.

Net return (ETB/ha): The treatments of net returns were obtained by subtracting the cost of treatments from the gross returns.

Cost benefit ratio (C: B) = cost of treatments (ETB)/Net return (ETB).

3.5. Data Analysis

The efficacy of the insecticides was calculated using Henderson Tilton's (1955) formula

$$\text{Corrected \%} = \left(1 - \frac{\text{n in Co before treatment} * \text{n in T after treatment}}{\text{n in Co after treatment} * \text{n in T before treatment}}\right) * 100$$

Where: n = Insect population, T = treated, Co = control

Data were subjected to analysis of variance (ANOVA) using the PROC-GLM procedure of SAS (Statistical Analysis System) version 9.0 (SAS Institute Inc., 2005) software.

Differences among treatment means were separated using Tukey's honestly range significant difference (HSD) at a 5% independent level of significance (Gomez and Gomez, 1984).

4. RESULTS AND DISCUSSION

4.1. Efficacy of Selected Bio-rational Insecticides against Cabbage Aphids

Infestation of cabbage aphids started within two weeks after transplanting. There was very high cabbage aphids infestation (84.6 - 87.9 aphids/plant) and (81.6 - 86.9 aphids/plant) before first application at Hawassa and Batu locations, respectively (Table 3 and 4). The number of aphid population was significantly reduced after the first application of biorational insecticides compared with untreated plots at Hawassa and Batu locations. Three days after the first insecticide spray, high reduction of aphid population on cabbage was recorded from plots treated with dimethoate 40% EC (6.5 and 4.3 aphids/plant) and Spinosad (11.1 and 8.4 aphid /plant) (Table 3 and 4). Reduction of aphid populations due to first application of Nimbecidine (9.7 aphids/ plant) and mixture of natural plant extracts and phytoenzyme (11.5 aphids/ plant) insecticides were not statistically different from dimethoate 40% EC and Spinosad treatments at Batu location (Table 4). On the other hand, Aphids count on mixture of natural plant extracts and phytoenzyme, Nimbecidine and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL was significantly higher than dimethoate 40% EC and Spinosad treated plots at Hawassa (Table 3). The least reduction of aphid population was recorded from cabbage plants treated with *M. ferruginea* aqueous crude water extract 51.0 and 42.1 aphids/ plant at Hawassa and Batu, respectively (Table 3 and 4).

Similar trends of performance were observed during the second round spray which was conducted after two weeks of the first spray. The pre-spray population density of insecticide sprayed plots was lower than the untreated plots and ranged from 59.6 to 81.8 and 51.6 and 83.5 aphids/ plant at Hawassa and Batu, respectively. On the other hand, high cabbage aphid population density was recorded in the untreated plots 345.6 and 249.8 aphids/ plant at Hawassa and Batu, respectively (Table 3 and 4). All the insecticides significantly reduced cabbage aphid population compared to the untreated plots. Few cabbage aphids survived (7.3-11.1 aphids/ plant at Hawassa and 4.4-7.2 aphids/ plant at Batu) on Spinosad, Nimbecidine and mixture of natural plant extracts and phytoenzyme treatments and were not significantly different from dimethoate 40% EC treated plots 1.9 and 1.8 aphids/ plant at Hawassa and Batu, respectively. On the other hand, *M. ferruginea* treatment caused the least aphid mortality compared with other insecticides in both locations (Table 3 and 4). The prior two applications of the insecticides had kept the population of the aphids to lower levels when assessed before treatment whereas aphid population on untreated plots increased in both locations. The third application of dimethoate 40% EC, Spinosad, mixture of natural plant extracts and phytoenzyme, Nimbecidine and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL reduced the population of aphids significantly to very low levels compared to the untreated plots. Similar to the first and second spray, Application of *M. ferruginea* caused the lowest cabbage aphid mortality compared to other treatments in both locations but significantly higher than from the untreated plots (Table 3 and 4).

Bio-rational (Spinosad, Nimbecidine and mixture of natural plant extracts and phytoenzyme) insecticide and the standard insecticide (dimethoate 40% CE) had more than 90% efficacy during the three sprays which indicated that they are equally effective (Table 5). The current results were similar with findings of Debbarma and Kumar (2020) that imidacloprid, thiamethoxam, Spinosad and acetamiprid were effective against *B. brassicae.* Sonia *et al.* (2020) reported that the highest reduction (97.66%) of aphid population was in Abamectin treated plants followed by Spinosad (93.75%), Emamectin benzoate (91.07%) and Lufenuron (89.45%) and Neem oil (71.68%), Neem products, such as Azadirachtin (Margosom) and Verticillium was also found effective for the management of cabbage aphid (Dhaliwal *et al.*, 1998; Rawat, 2006). Adhikari (2011) also reported that nimbecidine was also effective in reducing aphid population. According to report it showed an average control up to 48.22% in different sprays.

Spinosad showed high efficacy compared to *M. ferruginea* when tested in the experiment. Cabbage sprayed with Nimbecidine and mixture of natural plant extracts and phytoenzyme resulted in significantly lower proportion of damaged cabbage plants, and significantly higher cabbage head yield than the *Milletia* treatment and the untreated check. Similar findings with Sathupati and Anoorag (2019) reported that highest reduction of the aphid mean population was recorded from Spinosad treatments (63.38%) in first and (82.53%) in second spray.

Table 3. Population reduction of cabbage aphid at Hawassa during 2019/2020

Treatments	First spray		Second spray		Third spray	
	Pre spray	Post spray	Pre spray	Post spray	Pre spray	Post spray
	Mean number of aphids per plant					
Dimethoate 40% CE	85.0^{a}	6.5^{e}	59.6^{d}	1.9^{d}	36.9^{c}	0.6^{c}
Spinosad	84.6^{a}	11.1^{ed}	64.7^{cd}	7.3^{dc}	53.2^{cb}	4.9^{cb}
Nimbecidine	85.1^{a}	13.0^{d}	64.7^{cd}	8.5^{dc}	57.2^{cb}	5.9^{cb}
Mixture of natural plant extracts & phytoenzyme	85.6^{a}	15.2^{d}	74.6^{cb}	11.1^{dc}	67.3^{cb}	7.8^{cb}
S. flavescens plant extract 25% + Emamectin benzoate 1% SL	87.9^{a}	23.1^{c}	72.9^{cb}	20.8^{c}	76.4^{b}	16.6^{cb}
Milletia ferruginea	85.8^{a}	51.0^{b}	81.8^{b}	42.0^{b}	81.3^{b}	39.2^{b}
Untreated	86.4^{a}	172.8^{a}	345.6^{a}	591.4^{a}	882.7^{a}	1082.6^{a}
Tukey/HSD (0.05)	7.7	5.0	12.16	18.8	38.09	38.55
SE(m)	3.3	2.1	5.2	8.0	16.3	16.5

Means followed by the same letter(s) within a column are not significantly different at 5% Probability level using Tukey's honestly significant difference test; SE(m) = standard error of the mean

Table 4. Population reduction of cabbage aphid at Batu during 2019/2020

Treatments	First spray		Second spray		Third spray	
	Pre spray	Post spray	Pre spray	Post spray	Pre spray	Post spray
	Mean number of aphids per plant					
Dimethoate 40% EC	86.9^{a}	4.3^{d}	51.6^{c}	1.8^{c}	22.2^{d}	0.9^{c}
Spinosad	85.4^{a}	8.4^{dc}	61.2^{cb}	4.4^{c}	50.4^{cd}	5.4^{c}
Nimbecidine	81.6^{a}	9.7^{dc}	62.4^{cb}	5.6^{c}	62.1^{cb}	7.8^{c}
Mixture of natural plant extracts & phytoenzyme	84.8^{a}	11.5^{dc}	67.5^{cb}	7.2^{cb}	62.3^{cb}	9.2^{c}
S. flavescens plant extract 25% + Emamectin benzoate 1% SL	85.5^{a}	17.6^{c}	74.2^{cb}	11.8^{cb}	73.9^{cb}	17.8^{cb}
M. ferruginea	86.1^{a}	42.1^{b}	83.5^{b}	31.4^{b}	84.0^{cb}	44.2^{b}
Untreated	81.6^{a}	129.9^{a}	249.8^{a}	296.9^{a}	815.7^{a}	1256.4^{a}
Tukey/HSD (0.05)	9.93	10.45	25.05	24.28	30.45	26.5
SE(m)	4.25	4.47	10.72	10.4	13.0	11.34

Means followed by the same letter(s) within a column are not significantly different at 5% Probability level using Tu key's honestly significant difference test; SE(m) = standard error of the mean

Table 5. Efficacy percentage of biorational insecticide on cabbage aphid

Treatments	Location					
	Hawassa			Batu		
	First spray	Second spray	Third spray	First spray	Second spray	Third spray
	Percent Efficacy					
Dimethoate 40% EC	96.4	98.1	98.6	96.9	97.0	97.4
Spinosad	93.4	93.3	92.4	93.8	93.9	93.0
Nimbecidine	92.3	92.3	91.5	92.5	92.4	91.8
Mixture of natural plant extracts & phytoenzyme	91.0	91.2	90.5	91.4	91.4	90.8
S. flavescens plant extract 25% + Emamectin benzoate 1% SL	86.7	83.2	82.2	87.0	86.5	84.3
M. ferruginea	70.0	69.9	60.3	69.3	68.4	65.7

4.1.2. Yield Parameters

4.1.2.1. Head diameter

The highest cabbage head diameter was recorded from dimethoate 40% EC treated plots 12.3 and 12.9 cm at Hawassa and Batu locations, respectively, which were statistically non-significant with Spinosad (12.3 and 12.7), Nimbecidine (11.4 and 11.9) and mixture of natural plant extracts and phytoenzyme (11.3 and 11.6) treated plots at Hawassa and Batu location. Average cabbage head diameter of *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* treatments was significantly different from dimethoate 40% EC treatments. On the other hand, significantly lowest head diameter was recorded from untreated plots 7.8 and 7.8 cm at Hawassa and Batu, respectively (Table 6).

4.1.2.2 Marketable and unmarketable yield

There was a significant difference among treatments and untreated check but non-significant ($P<0.05$) difference was recoreded among Spinosad, Nimbecidine, a mixture of natural plant extracts and phytoenzyme when compared to the standard check except *S. flavescens* plant extract 25% + Emamectin benzoate 1% SL and *M. ferruginea* where it gave less marketable yield compared to other insecticide treatments at Hawassa. On the other hand, Spinosad treated plots were not statistically different with dimethoate 40% EC treated plots whereas a mixture of natural plant extracts and phytoenzyme, Nimbecidine, *S. flavescens* plant extract 25% + Emamectin benzoate 1% SL and *M. ferruginea* were significantly ($P<0.05$) different from dimethoate 40% EC treated plots in unmarketable yield at Batu (Table 6).

The highest marketable yield was obtained from Spinosad treated plots, 50.6 tons/ha at Hawassa and dimethoate 40% EC treated plots, 55.2 tons/ha Batu; followed by Nimbecidine, a mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* whereas the lowest marketable yield 3.5 and 2.5 tons/ha was obtained from the untreated control plots at Hawassa and Batu, respectively (Table 6). There was no significant (P<0.05) difference among *M. ferruginea* treatments and untreated check in unmarketable yield whereas other insecticide treatments resulted significantly (P<0.05) less unmarketable yield with the untreated plots. The highest unmarketable yield of cabbage was obtained from control plots 9.7and 8.9 t/ha Hawassa and Batu, respectively; followed by *M. ferruginea* and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL. The lowest unmarketable yield was obtained dimethoate 40% EC treated plots, 3.8 t/ha Hawassa and 3.2 t/ha Batu, respectively (Table 6).

4.1.2.3. Total yield

Regarding the total yield of head cabbage, the maximum total yield of head cabbage was obtained from dimethoate 40% EC treated plots, 57.6 tons/ha and 58.4 tons/ha, followed by Spinosad 55.4 and 56.4 tons/ ha at Hawassa and Batu, respectively; Nimbecidine 51.4 tons/ ha at Hawassa which was non-significantly (P<0.05) different among each other (Table 6). Nimbecidine treated plots at Batu, a mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* in both locations resulted significantly (P<0.05) less total yield when compared to the standard check). On the other hand, the lowest total yield of head cabbage 13.2 tons/ha and 11.4 tons/ha was obtained from untreated plots at Hawassa and Batu, respectively (Table 6).

The current results were similar with findings of (Sushil et al 2020) who reported the highest yield (66.47 mt/ ha) of cabbage head in dimethoate treated plots which was significantly at par with Derisom (58.79 mt/ ha) treated plots and dimethoate had 98.72 % increase in head yield over control while Derisom had 75.77% increase in yield over control. Jana *et al.* (1997) reported that reduction of aphid species with application of Dimethoate by 83.7 % over untreated check. The treatment of azadirachtin 0.0006% was found most effective followed by neem oil 0.3% and garlic bulb extract 3% for the control of aphid population, producing seed yield and net realization (Sarvaiya, et al., 2018). Bhat and Dhoj (2005) reported that control plots have very low marketable yield compared with treated plots.

Table 6. Effect of biorational insecticide application on yield of head cabbage at Hawassa and Batu locations

Treatments	head diameter (cm)		Marketable yield (tons/ha)		unmarketable yield (tons/ha)		Total yield (tons/ha)	
	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu
Dimethoate 40% EC	12.3^{a}	12.9^{a}	48.8^{a}	55.2^{a}	3.8^{e}	3.2^{d}	57.6^{a}	58.4^{a}
Spinosad	12.3^{a}	12.7^{ab}	50.6^{a}	51.3^{ab}	4.8^{de}	5.1^{cd}	55.4^{a}	56.4^{ab}
Mixture of natural plant extracts & phytoenzyme	11.3^{ab}	11.6^{abc}	39.8^{ab}	42.4^{c}	7.2^{bc}	6.6^{bc}	47.0^{b}	49.0^{c}
Nimbecidine	11.4^{ab}	11.9^{abc}	45.6^{a}	46.8^{bc}	5.8^{cd}	5.2^{cd}	51.4^{ab}	52.0^{bc}
S. flavescens plant extract 25% + Emamectin benzoate 1% SL	10.8^{bc}	11.4^{bc}	30.4^{b}	35.4^{d}	6.3^{dc}	6.4^{bc}	37.6^{c}	42.0^{d}
M. ferruginea	9.8^{c}	10.7^{c}	27.9^{b}	34.4^{d}	8.3^{ab}	7.6^{ab}	36.2^{c}	41.8^{d}
Untreated	7.8^{d}	7.8^{d}	3.5^{c}	2.5^{e}	9.7^{a}	8.9^{a}	13.2^{d}	11.4^{e}
Tukey/HSD (0.05)	1.1	1.4	11.9	6.8	2.0	2.2	8.1	6.1
SE(m)	0.5	0.6	5.0	3.0	0.8	1.0	3.4	6.1
CV (%)	4.6	5.4	14.4	7.7	12.6	15.4	8.1	5.8

Means followed by the same letter(s) within a column are not significantly different at 5% Probability level using Tukey's honestly significant difference test; SE(m) = standard error of the mean

4.1.3. Partial budget analysis

Cost of treatments (ETB/ha)

The highest cost of treatment was recorded from Spinosad (8000 birr/ha) followed by Nimbecidine (5000 birr/ha), mixture of natural plant extracts and phytoenzyme (4000 birr/ha), *S. flavescens* plant extract 25% + emamectin benzoate 1% SL (4000 birr/ha) and dimethoate 40% EC (3840 birr/ha) whereas the lowest cost of treatment was recorded from *M. ferrugeinea* treated plots (3000 birr/ha) in both locations (Table 7).

Gross return (ETB/ha)

The highest gross return was recorded from dimethoate 40% EC treatment, 693600 and 700800 birr/ha at Hawassa and Batu, respectively; followed by Spinosad, Nimbecidine, mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea*. The lowest gross return was recorded from untreated plots 158400 birr/ha and 136800 birr/ha in Hawassa and Batu, respectively (Table 7).

Net return (ETB/ha)

The highest net return was obtained from dimethoate 40% EC treated plots, 689760 birr/ha at Hawassa and 696960 birr/ha Batu; followed by Spinosad, Nimbecidine, mixture of natural plant extracts and phytoenzyme and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL whereas the lowest net return was recorded from *M. ferruginea* treated plots 431400 birr/ha and 498600 birr/ha at Hawassa and Batu, respectively (Table 7).

Cost benefit ratio(C: B)

The highest cost benefit ratio was from dimethoate 40% EC treated plots 1:180 and 1:182 at Hawassa and Batu locations, respectively; followed by *M. ferruginea*, mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL, Nimbecidine and Spinosad in both locations (Table 7).

Table 7. Partial budget analysis of different treatments

Treatments	Head yield (ton/ha)		Gross return (birr/ha)		Cost of treatment (birr/ha)		Net return (birr/ha)		Cost benefit ratio	
	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu
Mixture of natural plant extracts and phytoenzyme	47.0	49.0	564000	588000	4000	4000	560000	584000	1:140	1:146
Spinosad	55.4	56.4	664800	676800	8000	8000	656800	668800	1:82	1:84
M. ferruginea	36.2	41.8	434400	501600	3000	3000	431400	498600	1:144	1:166
Nimbecidine	51.4	52	616800	624000	5000	5000	611800	619000	1:122	1:124
S. flavescens plant extract 25% + Emamectin benzoate 1% SL	37.6	42	451200	504000	4000	4000	447200	500000	1:112	1:125
Dimethoate 40% EC	57.8	58.4	693600	700800	3840	3840	689760	696960	1:180	1:182
Untreated	13.2	11.4	158400	136800	-	-	-	-	-	-

Market price of cabbage heads 12 birr/Kg, cost of treatments also included application charges 500 birr/ha/spray

4.2. Efficacy of Selected Bio-rational and Synthetic Insecticides in Rotation against cabbage aphid

There was non-significant ($P<0.05$) difference among treatments with regard to the pre count of aphids/plant. There was very high cabbage aphids infestation (81.8-87.0 aphids/plant) and (83.0-88.6 aphids/plant) before first application at Hawassa and Batu, respectively. The first application of insecticides significantly ($P<0.05$) reduced the number of aphids compared with untreated plots (Table 8 and 9). However, Aphid population density after the first spray was the lowest on dimethoate 40% EC (4.5 aphids/ plant) treated plots; followed by Spinosad (9.0 aphids/ plant) and Nimbecidine (11.2 aphids/plant) treatments but not statistically different from dimethoate 40% EC protected plots at Hawassa. Post-spray aphid/ plant counts of a mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* were significantly ($P<0.05$) higher than the standard check (Table 8). Average count aphid/plant after the first spray of all bio-rational insecticides were significantly ($P<0.05$) higher as compared to the standard check at Batu location (Table 9). On the other hand, the number of aphid (148.3 aphids/ plant and 144 aphids/ plant) increased on the untreated plots in both locations (Table 8 and 9).

During the second spray low aphids/ plant post-spray count 1.15 – 8.7 aphids/ plant at Hawassa and 1.8- 7.3 aphids/ plant at Batu were recorded in all dimethoate 40% EC treatments and are not significantly ($P<0.05$) different from each other except on the *M. ferruginea* treated plots in rotation with dimethoate 40% EC where 27.1 and 22.8 aphids/ plant survived at Hawassa and Batu, respectively (Table 8 and 9). The third-round spray assessment showed that the cabbage aphid population density was significantly ($P<0.05$) higher on plots not protected with insecticides. Few aphids survived on dimethoate 40% EC treated plots and it was not significantly (P<0.05) different from Spinosad, a mixture of natural plant extracts and phytoenzyme, Nimbecidine and *S. flavescens* plant extract 25% +emamectin benzoate 1% SL treated plots at Batu (Table 9). Spinosad treated plots were equally effective with the standard check whereas aphid population density per plant after the spray in other insecticide treatments was significantly (P<0.05) higher when compared with dimethoate 40% EC at Hawassa (Table 8). The least mortality of cabbage aphids was from *M. ferruginea* treatments whereas the number of aphids increased which was 1043.6 and 1363.8 aphids/ plant at Hawassa and Batu, respectively (Table 8 and 9).

Efficacy of Spinosad, Nimbecidine and mixture of natural plant extracts and phytoenzyme was more than 90% which indicated that they were equally effective with the standard insecticide (dimethoate 40% EC) at Hawassa and Batu. During the three sequential sprays, the lowest efficacy was recorded from *M. ferruginea* 58.3 – 76.9% treatment (Table 10).

The study has shown that Spinosad, Nimbecidine and mixture of natural plant extracts and phytoenzyme have the potential to be used for the control of aphid on cabbage, which was equally effective with the standard check. Similar findings of Nakagome and Kato (1981) who identified that, all crop growth stages are exposed to stark aphid infestation, so insecticide applications are required to control aphid. Magallona (1985) also reported that insecticides are usually considered the most effective means of protective crops against insect damage as they provide rapid control of wide pest complex of major crucifer's pests, and growers worried about leaf damage, tend to spray insecticides.

Table 8. Effect of biorational insecticide and synthetic insecticide application on cabbage aphid at Hawassa during 2019/2020

Treatments	First spray		Second spray		Third spray	
	Pre spray	Post spray	Pre spray	Post spray	Pre spray	Post spray
	Mean number of aphids per plant					
N-D-N	82.7^{a}	11.2^{de}	68.6^{c}	6.9^{c}	63.9^{cb}	9.2^{d}
S-D-S	87.0^{a}	19.5^{c}	79.8^{b}	13.1^{cb}	71.8^{b}	20.6^{c}
M-D-M	85.8^{a}	13.2^{dc}	74.5^{cb}	8.3^{c}	67.6^{cb}	10.2^{d}
SP-D-SP	84.2^{a}	9.0^{de}	64.4^{c}	4.8^{c}	55.5^{cb}	6.6^{ed}
MI-D-MI	84.5^{a}	47.2^{b}	82.9^{b}	27.1^{b}	76.4^{b}	47.1^{b}
D-D-D	83.7^{a}	4.5^{e}	51.2^{d}	1.2^{c}	31.7^{c}	0.5^{e}
U	81.8^{a}	148.3^{a}	244.8^{a}	335.8^{a}	671.7^{a}	1043.6^{a}
Tukey/HSD (0.05)	7.4	8.1	10.6	17.4	35.9	6.4
SE(m)	3.2	3.4	4.5	7.4	15.3	2.7

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, SE (m) = standard error of the mean, N = Nimbecidine, S= *S. flavescens* plant extract 25% +emamectin benzoate 1% SL, M = mixture of natural plant extracts and phytoenzyme, SP= Spinosad, MI= *M. ferruginea*, D= dimethoate 40% EC) and U= untreated

Table 9. Effect of biorational insecticide and synthetic insecticide application on cabbage aphid at Batu during 2019/2020

Treatments	First spray		Second spray		Third spray	
	Pre spray	Post spray	Pre spray	Post spray	Pre spray	Post spray
	Mean number of aphids per plant					
N-D-N	85.4^{a}	11.0^{ed}	63.8^{cd}	5.2^{cb}	57.5^{cb}	6.9^{cb}
S-D-S	88.5^{a}	18.0^{c}	79.9^{cb}	10.8^{cb}	73.7^{cb}	15.1^{cb}
M-D-M	86.0^{a}	13.1^{d}	70.0^{cbd}	6.8^{cb}	62.1^{cb}	8.5^{cb}
SP-D-SP	83.0^{a}	8.5^{e}	61.8^{cd}	3.9^{cb}	51.1^{cd}	4.9^{cb}
MI-D-MI	87.9^{a}	45.9^{b}	83.8^{b}	22.8^{b}	79.0^{b}	38.9^{b}
D-D-D	84.2^{a}	3.8^{f}	50.8^{d}	1.1^{c}	30.5^{d}	1.2^{c}
U	85.4^{a}	144.0^{a}	881.9^{a}	453.5^{a}	919.4^{a}	1363.8^{a}
Tukey/HSD (0.05)	7.5	4.3	19.3	21.4	25.4	36.1
SE(m)	3.2	1.8	8.3	9.2	10.9	15.4

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, SE(m) = standard error of the mean, N = Nimbecidine, S= *S. flavescens* plant extract 25% +emamectin benzoate 1% SL, M = mixture of natural plant extracts and phytoenzyme,SP= Spinosad, MI= *M. ferruginea*, D= dimethoate 40% EC) and U= untreated

Table 10. Efficacy percentage of tested biorational insecticides and synthetic insecticide on cabbage aphid

Treatments	Location					
	Hawassa			Batu		
	First spray	Second spray	Third spray	First spray	Second spray	Third spray
	Percent Efficacy					
N-D-N	92.5	92.7	91.9	92.3	93.1	91.9
S-D-S	87.6	90.5	80.9	87.9	88.6	86.2
M-D-M	91.5	91.9	90.4	91.2	91.8	90.7
SP-D-SP	94.1	94.5	92.4	94.0	94.7	93.5
MI-D-MI	69.1	81.1	58.3	69.2	76.9	66.8
D-D-D	97.0	98.3	98.9	97.3	98.2	97.4

4.2.2. Yield parameters

4.2.2.1. Head diameter

The highest head diameter was recorded from sole dimethoate 40% EC treated plots 13.1and 13.2 cm at Hawassa and Batu locations, respectively, which was not significantly ($P<0.05$) different with Spinosad+dimethoate 40% EC and Nimbecidine+dimethoate 40% EC treated plots in both locations. Cabbage head diameter of a mixture of natural plant extracts and phytoenzyme+dimethoate 40% EC, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL+ dimethoate 40% EC and *M. ferruginea*+dimethoate 40% EC treatments was significantly ($P<0.05$) smaller when compared with sole dimethoate 40% EC treatment. The lowest head diameter was recorded from untreated plots 7.6 and 7.4 cm in both locations which is significantly ($P<0.05$) different from all insecticide treatments (Table 11).

4.2.2.4. Marketable and unmarketable yield (tons/ ha)

The highest marketable yield was obtained from three times dimethoate 40% EC treated plots (58.1 tons/ha at Hawassa and, 58.9 tons/ha Batu) and was significantly different from all other insecticide treatments at Batu whereas at Hawassa, Spinosad + dimethoate 40% EC and Nimbecidine+ dimethoate 40% EC were not significantly different from the marketable yield of standard check (dimethoate 40% EC). Marketable yield of all of the insecticide treatments were significantly superior from untreated plots, 3.5 and 3.3 tons/ha in Hawassa and Batu, respectively (Table 11). The highest unmarketable yield of cabbage was obtained from the untreated plots 9.1t/ha in both locations and was significantly different from insecticide treatments. The lowest unmarketable yield was obtained from dimethoate 40% EC treated plots, 2.5tons/ha Hawassa and 2.3 tons/ha Batu locations (Table 11).

The highest total yield of head cabbage was obtained from dimethoate 40% EC treated plots, 60.6 tons/ ha at Hawassa and 61.2 tons/ ha at Batu and was not significantly different from Spinosad + dimethoate 40% EC treatment in both locations and Nimbecidine+ dimethoate 40% EC at Hawassa. Total yield of head cabbage from the treatment of a mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* in rotation with dimethoate 40% EC were significantly lower than three time spray of standard insecticide (dimethoate 40% EC). On the other hand, the lowest total yield of head cabbage was recorded from the untreated plots, 12.8 tons/ha and 12.4 tons/ha at Hawassa and Batu, respectively (Table 11).

Plots treated with recommended insecticides dimethoate 40% EC had the lowest aphid leaf damage the highest head yields. The maximum marketable cabbage yield of 111.90 t/ha was recorded from two insecticide combination rate of Diazinon 0.25%+ Dimethoate 0. 5%m treatment plots. Also the lowest unmarketable yield 17.67 t/ha were gotten from the best treated plot with a combination of Diazinon 0.25%+ Dimethoate 0. 5% (Belaynesh, 2018).

Table 11. Effect of tested biorational insecticide and synthetic insecticide application on head cabbage yield

Treatments	Head diameter (cm)		Marketable (tons/ha)		Unmarketable yield (tons/ha)		Total yield (tons/ha)	
	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu
N-D-N	12.2^{a}	12.0^{a}	52.4^{ba}	52.8^{b}	4.3^{cd}	3.9^{cd}	56.6^{ba}	56.7^{bc}
S-D-S	10.4^{b}	10.4^{b}	43.6^{dc}	44.2^{d}	5.4^{cb}	5.0^{cb}	49.0^{dc}	49.2^{de}
M-D-M	10.9^{b}	10.9^{b}	47.7^{bc}	48.7^{c}	4.7^{cd}	4.5^{cb}	52.4^{bc}	53.2^{dc}
SP-D-SP	12.4^{a}	12.5^{a}	52.7^{ba}	54.3^{b}	3.7^{ed}	3.3^{ed}	56.4^{ba}	57.6^{ba}
MI-D-MI	10.3^{b}	10.3^{b}	37.3^{d}	42.2^{d}	6.1^{b}	5.6^{b}	43.4^{d}	47.8^{e}
D-D-D	13.1^{a}	13.2^{a}	58.1^{a}	58.9^{a}	2.5^{e}	2.3^{e}	60.6^{a}	61.2^{a}
U	7.6^{c}	7.4^{c}	3.5^{e}	3.3^{e}	9.1^{a}	9.1^{a}	12.8^{e}	12.4^{f}
Tukey/HSD (0.05)	1.11	1.1	6.4	4.0	1.3	1.2	6.5	4.0
SE(m)	0.5	0.5	2.8	1.7	0.6	0.5	2.79	1.8

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, SE(m) = standard error of the mean, N = Nimbecidine, S= *S. flavescens* plant extract 25% +emamectin benzoate 1% SL, M = mixture of natural plant extracts and phytoenzyme, SP= Spinosad, MI= *M. ferruginea*, D= dimethoate 40% EC) and U= untreated

4.2.3. Partial budget analysis

Cost of treatments (ETB/ha)

The highest cost of treatment was recorded from Spinosad+ dimethoate 40% EC (4600 birr/ha) followed by Nimbecidine+ dimethoate 40% EC, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL+ dimethoate 40% EC mixture of natural plant extracts and phytoenzyme+

dimethoate 40% EC and dimethoate 40% EC whereas the lowest cost of treatment was recorded from *M. ferrugeinea* treated plots (3820 birr/ha) in both locations (Table 12).

Gross return (ETB/ha)

The highest gross return was recorded from dimethoate 40% EC, 727200 birr/ha at Hawassa and 734400 birr/ha Batu; followed by Nimbecidine+ dimethoate 40% EC,Spinosad+ dimethoate 40% EC, mixture of natural plant extracts and phytoenzyme+ dimethoate 40% EC, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL+ dimethoate 40% EC and *M. ferruginea*+ dimethoate 40% EC. The lowest gross return was recorded from untreated plots 153600 birr/ha and 148800 birr/ha in Hawassa and Batu, respectively (Table 12).

Net return (ETB/ha

The highest net return was obtained from dimethoate 40% EC treated plots, 723360 birr/ha and 730560 birr/ha at Hawassa and Batu, respectively; followed by Spinosad+ dimethoate 40% EC at Batu, Nimbecidine+ dimethoate 40% EC at Hawassa, mixture of natural plant extracts and phytoenzyme+ dimethoate 40% EC and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL+ dimethoate 40% EC whereas the lowest net return was recorded from *M. ferruginea*+ dimethoate 40% EC treated plots 516980 birr/ha and 569780 birr/ha at Hawassa and Batu, respectively (Table 12).

Cost benefit ratio(C: B)

The highest cost benefit ratio was recorded from dimethoate 40% EC treated plots 1:188 and 1:190 at Hawassa and Batu locations, respectively; followed by Nimbecidine+ dimethoate 40% EC, Spinosad+ dimethoate 40% EC, mixture of natural plant extracts and phytoenzyme+

dimethoate 40% EC, *M. ferruginea*+ dimethoate 40% EC and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL+ dimethoate 40% EC in both locations (Table 12).

Table 12. Partial budget analysis of different treatments

Treatments	Head yield (ton/ha)		Gross return (birr/ha)		Cost of treatment (birr/ha)		Net return (birr/ha)		Cost benefit ratio	
	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu	Hawassa	Batu
N-D-N	56.6	56.7	679200	680400	4560	4560	674640	675840	1:148	1:148
S-D-S	49.0	49.2	588000	590400	4540	4540	583460	585860	1:128	1:129
M-D-M	52.4	53.2	628800	638400	4280	4280	624520	634120	1:146	1:148
SP-D-SP	56.4	57.6	676800	691200	4600	4600	672200	686600	1:146	1:149
MI-D-MI	43.4	47.8	520800	573600	3820	3820	516980	569780	1:135	1:149
D-D-D	60.6	61.2	727200	734400	3840	3840	723360	730560	1:188	1:190
U	12.8	12.4	153600	148800	-	-	-	-		

Market price of cabbage heads 12 birr/Kg, cost of treatments also included application charges 500 birr/ha/spray

5. CONCLUSION AND RECOMMENDATIONS

The current study was aimed to evaluate the efficacy of selected bio-rationales and their use with synthetic insecticides in rotation against cabbage aphids. The results in both locations showed that the efficacy of spinosad, nimbecidine, and a mixture of natural plant extracts and phytoenzyme were comparable with the standard check (dimethoate 40% EC) which was greater than 90% *and gave a high yield.* On the other hand, three times S. *flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* crude water extract applications caused a highly significant reduction in aphid population compared with untreated control but not equally effective as a standard check (dimethoate 40% EC). Yield of head cabbage obtained from spinosad, nimbecidine, and a mixture of natural plant extracts and phytoenzyme protected plots was equivalent to plots protected with the standard check (dimethoate 40% EC). The *S. flavescens* plant extracts 25% + emamectin benzoate 1% SL and *M. ferruginea* treatments had lower efficacy (<90%) and significantly less yield compared to dimethoate 40% EC, spinosad, nimbecidine, and a mixture of natural plant extracts and phytoenzyme treated plots.

The efficacy of spinosad, Nimbecidine, and a mixture of natural plant extracts and phytoenzyme sprayed in rotation with dimethoate 40% EC were comparable and effective when compared to the sole use of synthetic insecticide (dimethoate 40% EC) in reducing cabbage aphid population. The highest yield was obtained from the sole use of standard check (dimethoate 40% EC) followed by plots protected with the use of Spinosad in both locations and, Nimbecidine at Hawassa sprayed in rotation with dimethoate 40% EC but not significantly different from the standard check. A use of spinosad, nimbecidine, and a mixture of natural plant extracts and phytoenzyme sprayed in rotation with dimethoate 40% EC can be recommended as an alternative way for the control of cabbage aphid, *Brevicoryne brassicae* (L.).

Both experiments showed that all insecticides significantly reduced cabbage aphid population when compared with the untreated plots. Some bio-rational insecticides like spinosad, nimbecidine, and a mixture of natural plant extracts and phytoenzyme were as effective as dimethoate 40% EC in cabbage aphid control. Bio-rationales in rotation with synthetic insecticides also gave control of the cabbage aphid population and resulted in better yield. However, the current experiments were based on only two locations with few bio-rational insecticides and synthetic insecticides were tested. Therefore, studies on the use of various bio-rational insecticides in rotation with synthetic insecticides should be tested across different agroecological zones. Future studies and interventions should be designed to study insecticide resistance and develop resistance management solutions.

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7. APPENDICES

Appendix Table 1. Experiment one, Mean square values of pre- and post-spray count aphid during first spray at Hawassa and Batu

Source of variation	D.F	Hawassa Pre spray means	Hawassa Post spray means	Batu Pre spray means	Batu Post spray means
Treatment	6	4.85^{ns}	14217.3***	17.8^{ns}	8092.5***
Replication	3				
Error	18				

*** = highly significant at p<0.0001, ns = non- significant and D. F= degree of freedom.

Appendix Table 2. Experiment one, Mean square values of pre- and post-spray count aphid during second spray at Hawassa and Batu

Source of variation	D.F	Hawassa Pre spray means	Hawassa Post spray means	Batu Pre spray means	Batu Post spray means
Treatment	6	43719.3***	190368.4***	19551.0***	47314.5***
Replication	3				
Error	18				

*** = highly significant at p<0.0001, ns = non- significant and D. F= degree of freedom.

Appendix Table 3. Experiment one, Mean square values of pre- and post-spray count aphid during third spray at Hawassa and Batu

Source of variation	D.F	Hawassa Pre spray means	Hawassa Post spray means	Batu Pre spray means	Batu Post spray means
Treatment	6	385762.8***	654962.8***	328215.3***	882584.9***
Replication	3				
Error	18				

*** = highly significant at p<0.0001, ns = non- significant and D. F= degree of freedom.

Appendix Table 4. Experiment one, Mean square of analysis of variance for yield parameters at Hawassa and Batu

Source of variation	Hawassa				Batu		
	D.F	HD	HW	HY	WD	HW	HY
Treatment	6	9.8***	371.0***	948.0***	11.7***	396.0***	1013.6***
Replication	3						
Error	18						

HD = Head diameter, HW=Head weight, HY=Head yield, *** = highly significant at (p<0.0001).

Appendix Table 5. Experiment two, Mean square values of pre- and post-spray count of aphid during first spray at Hawassa and Batu

Source of variation	Hawassa			Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	6	12.74 ^{ns}	10583.8***	15.3 ^{ns}	10015.2***
Replication	3				
Error	18				

*** = highly significant at p<0.0001, ns = non- significant and D. F= degree of freedom.

Appendix Table 6. Experiment two, Mean square values of pre- and post-spray count of aphid during second spray at Hawassa and Batu

Source of variation	Hawassa			Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	6	17888.7***	60860.1***	56694.7***	113378.6***
Replication	3				
Error	18				

*** = highly significant at p<0.0001, ns = non- significant and D. F= degree of freedom.

Appendix Table 7. Experiment two, Mean square values of pre- and post-spray count of aphid during third spray at Hawassa and Batu

Source of variation		Hawassa		Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	6	213891.2***	604825.4***	424062.7***	
Replication	3				
Error	18				

*** = highly significant at p<0.0001, ns = non- significant and D. F= degree of freedom.

Appendix Table 8. Experiment two, Mean square of analysis of variance for yield parameters at Hawassa and Batu

Source of variation		Hawassa			Batu		
	D.F	HD	HW	HY	WD	HW	HY
Treatment	6	13.7***	411.6***	1053.7***	14.7***	426.5***	1091.6***
Replication	3						
Error	18						

HD = Head diameter, HW=Head weight, HY=Head yield, *** = highly significant at (p<0.0001).

Appendix figure 1.Data recording and spray insecticides

BIOGRAPHICAL SKETCH

The author was born on the 7th of December 1989 at a small village called Messafe Kebele in Kachabira Wereda, Kambata Tembaro Zone of Southern Nation, Nationality and Peoples' Regional State (SNNPRS), Ethiopia from her father Adnew Aloto and her mother Bogalech Tesiso. She attended her elementary education at Kuya'a Primary School from 1996-2003 and secondary and preparatory education at Durame Secondary and Preparatory School from 2004-2007. After successful passing the Ethiopian School Leaving Certificate Examination (E.S.L.C.E), she joined Dilla University in 2008 and graduated with the Degree of Bachelor of Science in Plant Science in July 2010. She worked in Governmental Organization in Kachabira woreda at five years. She assigned to work as soil fertility expert and root and vegetable expert. In 2017 she joined the school of graduate study at Hawassa University to pursue her M.Sc. degree in crop protection. She is married and a mother of two girls and one boy.