EFFECTIVENESS OF SOME BOTANICALS IN CONTROLLING MAJOR LEPIDOPTERAN INSECT PESTS OF SUMMER CABBAGE

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CERTIFICATE

*This is to certify that the thesis entitled, "**EFFECTIVENESS OF SOME BOTANICALS IN CONTROLLING MAJOR LEPIDOPTERAN INSECT PESTS OF SUMMER CABBAGE**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **ENTOMOLOGY**, embodies the result of a piece of bona fide research work carried out by **Md. Emam Hossain, Registration No. 13-05718** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: June, 2020

Dhaka, Bangladesh

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ABSTRACT

An experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from May, 2018 to September, 2018 to evaluate some botanicals applied against major insect pests of summer cabbage. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications .Seven treatments, viz., T_1 (Mahogany seed kernel extract @ 3.0 ml/L of water at 7 days interval); T_2 (Tobacco leaf extract @ 3.0 ml/L of water at 7 days interval); T_3 (Garlic extract @ 3.0 ml/L of water at 7 days interval); T_4 (Neem leaf extract @ 3.0 ml/L of water at 7 days interval); T_5 (Neem seed kernel extract @ 3.0 ml/L of water at 7 days interval); T_6 (Neem oil @ 3.0 ml/L of water at 7 days interval) and T_7 (untreated control) were used. Among the management practices, the lowest mean infestation of cabbage leaf by semi-looper (4.79 leaves/5 plants), tobacco caterpillar (6.25 leaves/5 plants) and diamond back moth larvae 4.39 leaves/5 plants) was found in T_6 that reduced highest leaf infestation over control (59.40%, 61.73% and 68.03% respectively); whereas the highest infestation by semi-looper (11.80 leaves/5 plants), tobacco caterpillar (16.33 leaves/5 plants) and diamond back moth larvae (13.73 leaves/5 plants) was found in $T_{7.}$ The lowest mean incidence of semi-looper (5.47 larvae/5 plants), tobacco caterpillar (9.17 larvae/5 plants) and diamondback moth (3.30 larvae/5 plants) was found in T_6 that reduced highest incidence over control (65.09%, 49.97% and 66.57% respectively); whereas the highest values of all these parameters were recorded from untreated control treatment (T_7).The lowest cabbage head infestation(13.00%) was recorded in T_6, that gave the highest yield of cabbage (36.50 tha^{-1}) followed by T_4 (31.83 tha^{-1}). From the study it was found that there is a strong negative relationship between leaf infestation intensity and single head weight and between leaf infestation intensity and yield (tha^{-1}) of cabbage. Moreover, a strong negative relationship was observed between percent head infestation and weight of individual head at harvest.

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ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
CV %	=	Percent Coefficient of Variation
DAT	=	Days After Transplanting
e.g.	=	exempli gratia (L), for example
et al.,	=	And others
etc.	=	Etcetera
FAO	=	Food and Agricultural Organization
g	=	Gram (s)
GM	=	Geometric mean
i.e.	=	id est (L), that is
K	=	Potassium
Kg	=	Kilogram (s)
L	=	Litre
LSD	=	Least Significant Difference
M.S.	=	Master of Science
m^2	=	Meter squares
mg	=	Mili gram
ml	=	Mili Litre
P	=	Phosphorus
SAU	=	Sher-e-Bangla Agricultural University
var.	=	Variety
WHO	=	World Health Organization
μg	=	Microgram

CHAPTER I

INTRODUCTION

Cabbage, *Brassica oleracea* var. *capitata* L., is one of the most unique cruciferous vegetables grown extensively in tropical and temperate regions of the world (Sarker *et al*., 2002). It is also a well-known and widely distributed crop within Asia and has been introduced successfully into parts of Central America, West Africa, America, Canada and Europe (Talekar and Selleck, 1982). Vegetable production in Bangladesh is far below the actual requirements. In 2016-2017, total vegetable (summer and winter season) production area was 1025 thousand acres with total production of 4.048 million tons (BBS, 2017). The consumption rate of vegetables in our country is 33 kg/head/yr, but in developed countries it is 7-8 times higher (FAO, 2015). FAO (2015) claimed that at least 5% of total calories should have come from vegetables and fruits, which may fulfill the requirement of vitamins and minerals of the body.

In Bangladesh, cabbage is locally known as ‘Badha Kopi’ or ‘Pata Kopi’ and the most common vegetable crop grown from seed. It is one of the five leading vegetables in the country which belong to the Cruciferae family. It has been recognized as a very important commercial vegetable to the farmers in providing income and nutrition worldwide (Oruku and Ndungu, 2001, Kfir, 2004, Lohr and Kfir, 2004, FAOSTAT, 2007). The medicinal values of cabbage include treatment of constipation, stomach ulcers, headache, excess weight, skin disorders, eczema, jaundice, scurvy, rheumatism, arthritis, gout, eye disorders, heart diseases, ageing and Alzeimer’s disease (Tanongkankit *et al*., 2011).

Cabbage can play a vital role in elevating the nutritional status of Bangladesh, as it is rich in vitamins and minerals such as carotene, ascorbic acid and contains appreciable quantities of thiamin, riboflavin, calcium and iron (Thompson and Kelly, 1988). It has been reported that 100 g of edible portion of cabbage contains 92% water, 24 calories of food energy, 1.5 g of protein, 9.8 g of carbohydrate, 40 mg of Ca, 0.6 mg of Fe, 600 IU of Carotene, 0.05 mg of thiamine, 0.05 mg of riboflavin, 0.3 mg of niacin and 60 mg of vitamin E (Rashid, 1993).

Moreover, it is a rich source of vitamins A and C (Prabhakar and Srinivas, 1990 and Tiwari *et al*., 2003). It may be served in slaw, salads or cooked dishes (Andersen, 2000). The yield of cabbage in Bangladesh is 16.84 metric tha^{-1} and total production across the country was 311650 metric ton (BBS, 2017). The yield of cabbage in Bangladesh is 75-100 $tonha^{-1}$ depending on selection of variety and season (Rashid *et al.*, 2006).

These yields are low compared to other developing countries. However, low yield may be attributed to a number of reasons viz., unavailability of quality seeds of high yielding varieties, delayed sowing after the harvest of transplanted aman rice, fertilizer management, improper or limited irrigation facilities and due to the attack of insect pests.

Insect pests play an important role in decreasing the production of cabbage in Bangladesh. Many insect pests damage the cabbage crop (*Brassica oleracea* var. *capitata* L.). Among them, Lepidopterous insects such as cabbage semi-looper (*Trichoplusia ni* Hub.), diamondback moth (*Plutella xylostella* L.), tobacco caterpillar/prodenia caterpillar (*Spodoptera litura* Fab.), are the most destructive insect pests of cabbage (Iqbal *et al.,* 2015). Cabbage looper (*Trichoplusia ni* Hub.) is one of the most destructive pests, which destroys leaves of cabbage by voraciously feeding. They deposite eggs on the underside of leaves near the leaf edge. The large caterpillars are extremely voracious and cause damage by chewing the leaves and making holes on the cabbage head (Natwick *et al.,* 2017). Tobacco caterpillar (*Spodoptera litura* Fab.) is a polyphagous pest and cause considerable damage to vegetables (Srivastava *et al*., 2018). It is one of the important insect pests of Agricultural crops in the Asian tropics and the pest was found to occur in cabbage growing areas (Reddy *et al.,* 2017). It can reduce more than 50% yield in some cabbage genotypes (Bhat *et al.,* 1994). In Bangladesh, Ahmed (2008) reported that tobacco caterpillar causes damage 3.99% to 13.44% on leaves and 23.33% to 58.33% on plants depending on the varieties.

Diamondback moth (*Plutella xylostella* L.) is a primary pest causing heavy loss of the cabbage field by larval feeding (Parajuli and Paudel, 2019).

The adult diamondback moth lay eggs on the underside of lower leaves singly or in the cluster. Larvae feed on the whole plant parts but it mostly feeds around the bud of small transplants. The young larvae crawl and make mine between the lower and upper leaf areas and older larvae create irregular short mines while leaving the upper surface intact (Iqbal *et al.,* 2015). Damage caused by diamondback moth (*Plutella xylostella* L.) on the head of cabbage was assessed and yield losses up to 12.00 and 20.7ton ha^{-1} in the first season and 27.00 and 48.7ton ha^{-1}, respectively in the second season (Bhatia, 1994). Yield loss (up to 30%) due to the competition may be tolerable as an alternative to severe pest damage, in situations where infestation levels are high. These insect pests cause more serious damage to cabbage in the summer season (Andrea, 2006).

Though cabbage is mostly grown in the winter season, it can be grown in summer also with necessary management (Smith *et al.,* 1988). From Bangladesh's perspective, evidence was found that cabbage can be grown successfully in the summer season also. In 2011, farmers of Jibon Nagar Upazila in Chuadanga district, produced a variety of summer cabbage (KKR) which was imported from Japan and the production was very satisfactory. Mukaiede Yoko, a vegetable specialist of the Taki and Company (Japan) suggested bringing the cabbage cultivation under ecofriendly management instead of using synthetic chemical insecticides for the sake of safety to public health (Aman, 2011).

However, Pest management is facing economic and ecological challenges worldwide due to human and environmental hazards caused by the majority of synthetic chemical pesticides. Indiscriminate use of chemical pesticides resulted in problems like the development of resistance to pesticides, secondary pest outbreak, pest resurgence, bioaccumulation of chemicals in the food chain, environmental pollution, human health hazards, and destruction of non-target organisms. The use of safer chemicals such as botanicals is drawing attention throughout the world as more compatible substitutes to the highly persistent synthetic pesticides.

Hence, biorational approaches by utilizing botanical preparations and natural products are gaining significance as possible alternative measures for the eco-friendly management of insect-pests (Joshi *et al.,* 2020).

Botanical pesticides have a proven track record and long use for pest control and have spun off important groups of synthetic pesticides such as pyrethroids and neonicotinoids. While botanicals are now a small part of the overall pesticide market due to replacement by synthetics, the new environmental movement has provided a favorable environment for the rebirth of botanical insecticides. The public concern about using botanicals over synthetic insecticides is growing.

This has led to the large growth in organic agriculture where the industry self-regulates the use of products restricting synthetics but allowing some botanical pest control (Dey *et al.,* 2017). The use of botanical pesticides is now emerging as one of the prime means to protect crops and their products and the environment from pesticide pollution. Botanicals degrade more rapidly than most chemical pesticides, and are, therefore, considered relatively environment friendly and less likely to kill beneficial pests as compared to broad spectrum synthetic pesticides. Several plant substances have been considered for use as pest antifeedants, repellents, and toxicants (Joshy *et al.,* 2020).

There are several methods to combat insect pests of cabbage comprising cultural, mechanical, chemical, biological, botanicals and host plant resistance. Traditionally, the farmers of Bangladesh use chemical insecticides indiscriminately to combat these pests of cabbage without considering doses and negative impact of insecticides on non-target organisms and economic injury level of the pests. These chemical control of the insect pests of cabbage is not only expensive but also left-over residues on the sprayed surface of the crops and/or in the soil, destroying natural enemies have become a matter of great concern of human health and environmental pollution (Rikabdar, 2000). Considering the hazards of chemical insecticides, the utilization of botanicals is the safe and hazards free tactics for the environmental pollution free management of insect pests (Hasan *et al.,* 1960).

Among the botanicals viz., neem oil, neem leaf extract, neem seed kernel extract, garlic extract etc. are widely used for controlling the insect pests of cabbage. These are safe for environment, human health & beneficial insects and also cheaper. But these botanicals are used in vegetable cultivation without knowing the appropriate botanicals as well as their optimum doses. In such a situation it was strongly felt to assess the present status of botanicals against major Lepidopteran insect pests of summer cabbage under field conditions of the cabbage. Therefore, the present study was undertaken to fulfill the following objectives:

- to assess the level of infestation caused by major Lepidopteran insect pests of summer cabbage, and
- to find out the efficacy of botanicals in managing major Lepidopteran insect pests of summer cabbage.

CHAPTER II

REVIEW OF LITERATURE

Cabbage is one of the most leading vegetables in Bangladesh. Vegetable production in the country is far below actual requirements, so the demand of vegetables is increasing day by day. For this reason, the horizontal expansion of vegetable yield ha^{-1} should be increased to meet this ever-increasing demand for vegetables. But vegetable cultivation faces various problems including pest management. Cabbage is infested by a large number of insect pests in the field, which causes significant yield loss in every year.

Among the insect pests, Lepidopteran insects like cabbage semi-looper, diamondback moth, tobacco caterpillar are the major insect pests of cabbage. An attempt has been taken in this chapter to review the pertinent literature related to the present study. The information is given below under the following sub-headings.

2.1. General review of insect pest of cabbage

2.1.1. Cabbage semi-looper

The cabbage semi-looper (*Trichoplusia ni*) is a member of the moth family Noctuidae belongs to the order of Lepidoptera. It is found throughout the southern palearctic ecozone, all of North America, part of Africa and most of the Oriental and Indo-Australian region (Akhtar *et al.,* 2008).

2.1.1.1 Systematic position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Trichoplusia*

Species: *Trichoplusia ni*

2.1.1.2 Origin and distribution

The cabbage semi-looper (*Trichoplusia ni*) is native to the United States and feeds on many vegetable plants including all members of the cabbage family (Brassicaceae). This insect cannot over winter in the Midwest. Adult cabbage semi-looper moths annually migrate to the North United States and Canada from early July to late August, depending on the weather and airflow patterns. There can be 1 to 3 generations during the growing season in the northern states depending on arrival time and late summer temperatures (Hutchison *et al.,* 1999).

The cabbage semi-looper (*Trichoplusia ni*) is found throughout North America. It is a major pest of crucifer crops including cabbage, broccoli and cauliflower. It may also be found feeding on the agricultural crops such as beets, celery, lettuce, peas, spinach, tomatoes and flowers including camations and nasturtiums. Cabbage semi-looper cannot survive Canadian winters. Every year, they migrate from the Southern US and arrive here in July and August depending on temperatures and air flow patterns. Although they normally produce two to three overlapping generations in a growing season, the actual number depends on when they arrive in Canada. And it takes approximately one month of warm weather for the cabbage semi-looper to complete its life cycle and to produce the next generation of offspring (Dedes, 2003).

Cabbage semi-looper is one of the most important annual pests for Florida cabbage growers. It is less of a problem in southern Florida, where it is considered a minor pest. In that part of the state, pheromone trap data show that adult populations tend to be highest during the late spring and summer months and in some years in the late fall (Nuessly and Hentz, 1999). Cabbage semi-looper does not enter diapauses and cannot survive prolonged cold weather. The insect remains active and reproduces throughout the winter months only in the southern part of Florida (South of Orlando) (Capinera, 1999a). In central Florida, cabbage semi-looper populations peak during early fall and again during late spring (Leibee, 1996). In general, cabbage semi-looper is more of a problem on Florida cabbage during the fall than during the winter or spring months.

The cabbage semi-looper, *Trichoplusia ni*, Hub., (Lepidoptera: Noctuidae) is a cosmopolitan insect pest that causes damage in more than 160 species of plants (Sutherland and Greene,1984), and has become a chronic pest of Canadian greenhouse vegetable crops.

2.1.1.3 Nature of damage

Cabbage semi-looper larvae damage plants by chewing holes in leaves. Smaller larvae remain on the lower leaf surface, while larger larvae produce larger holes throughout the leaf. In addition to feeding on the wrapper leaves, cabbage loopers may bore into the developing head. Some defoliation can be tolerated before head formation, but feeding damage and excrement left behind on heads make cabbage unmarketable. Cabbage with damage confined to wrapper leaves is marketable but with reduced value. Control has been shown to the justified in Texas when population densities reach 0.3 larvae plant^{-1} (Capinera, 1999a). In Florida, an action threshold of 0.1 medium to large cabbage looper larvae per plant was developed for cabbage (Leibee, 1996).

2.1.2. Diamondback moth

The diamondback moth, *Plutella xylostella* belongs to the order Lepidoptera and the family Plutellidae.

2.1.2.1 Systematic position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Plutellidae

Genus: *Plutella*

Species: *Plutella xylostella*

2.1.2.2 Origin and distribution

The diamondback moth (*Plutella xylostella*), sometimes called cabbage moth, is a European moth believed to originate in the Mediterranean region that has since spread worldwide. The moth has a short life cycle (14 days at 25°C), highly fecund and capable of migrating long distances. It is one of the most important pests of cole crops in the world and will usually only feed on plants that produce glucosinolates (Talekar and Shelton, 1993).

2.1.2.3 Nature of damage

From May to September, *Plutella xylostella* (L.) (diamondback moth) poses the greatest threat to production (Walsh and Furlong, 2008). The larval stage of the diamondback moth (DBM) makes numerous small holes in the leaves, and sometimes leaves fine webbing in the center of the plant. Foliar injury lowers the quality of the crop, and weakens the plant. The larvae themselves can be a contaminant of the final product. Of the three lepidopteron pests of cabbage, DBM is comparatively difficult to control in New York (Moyer, 1999). It usually devours only a small portion of leaf. Larvae work on the underside and eat many and produce small holes. Frequently they live only the upper epidermis, which has an isinglass-like effect (Janmaat, 2003).

2.1.3 Tobacco caterpillar (*Spodoptera litura*)

The tobacco caterpillar, *Spodoptera litura* belongs to the order Lepidoptera of the family Noctuidae.

2.1.3.1 Systematic position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Spodoptera*

Species: *Spodoptera litura*

2.1.3.2 Origin and distribution

The tobacco caterpillar is found throughout the tropical and subtropical parts of the world. It is wide spread in India (Atwal, 1986). This pest has been reported from India, Pakistan, Ceylon, Burma, Thailand, Malaysia, Cambodia, Laos, Vietnam, Sabah, Indonesia, the Philippines, Taiwan, Queensland, New South Wales, New Guinea, Papua, West Iran, Solomon Islands, Gilbert Islands, New Caledonia, Fiji, Samoa, Tonga, Society Islands and Micronesia (Grist and Lever, 1989). The two old world cotton leaf worm species, *Spodoptera litura* and *Spodoptera littoralis*, are allopatric, their ranges covering Asia and Africa, respectively (Hill, 1983).

2.1.3.3 Nature of damage

Tobacco caterpillar *Spodoptera litura* attack the tender leaves, larva cause the damage only. The female moth of tobacco caterpillar lay eggs on the lower surface of the leaves. After hatching of the eggs, the tiny caterpillar starts feeding on host plant. In the early stage of cabbage that is the head forming stage the infestation is found to occur which cause a greater damage. In this stage caterpillars bored the new forming head and reached to the newly emerging little leaf and consumed it. As a result, main head of cabbage cannot form. Due to the cosmetic nature of cabbage, a hole is enough to devaluate it. In market it is sold in reduced price (Reddy *et al.*, 2017).

Because of the excreta is left at the damaged site sometimes it causes rotting in the inner portion of cabbage. The nature of damage and extent of damage differ with age of the caterpillars. The young caterpillar along with mature caterpillar also cause greater damage if the infestation occurs at the head forming stage. In field, later stage of cabbage is not found to be infested. Succeeding generations can do greater damage and later instars larvae remain outside the cabbage head, can come out as a serious phase of infestation for their voracious eating habit (Tofael, 2004).

2.2 Management of insect pests of cabbage

2.2.1 Cultural control

Cultural controls that can reduce pest populations consist of a variety of management practices such as crop rotation, cultivation, weed management, water management, and proper fertilizer use. Using fallow periods and crop rotation can interrupt the life cycles of pests whenever possible. Always destroy plant debris that can harbor pests and control weeds because they attract insects that may feed on vegetation. Intercropping is the practice of 'increasing crop diversity' by growing more than one plant species in a field to overcome insect pest outbreak problems associated with monocultures. Dempster (1969) studied the effects of weed control in brussels sprouts on *P. rapae* and found that weeds provide a habitat for predators of the caterpillar. However, yield reduction due to weed competition outweighed the advantageous effects of insect control obtained in the weedy plots. Buranday and Rarest (1975) compared the abundance of adults and oviposition of *P. xylostella* in a cabbage field and in a field with cabbage and tomato intercropped. Both factors were lower in the intercropped field and it was suggested that volatile compounds emitted by the tomatoes repelled the adult moths. The recommended planting pattern is two cabbage rows between two rows of tomato. The pest control benefits with respect to reduction in larval feeding damage were not assessed as plots were sprayed regularly with *B. thuringiensis,* masking of tomato and larvae. In another study, numbers of *P. xylostella* larvae and pupae were reduced by intercropping cabbage with tomato, barley, dill, garlic, oats or safflower (Talekar *et al*., 1986).

Kenny and Chapman (1988) assessed an intercrop of cabbage and dill (*Anethum graveolens* L.). The number of cabbage aphids on cabbages planted near dill was lower than those planted without dill. Results for numbers of *P. rapae* and *Plutella xylostella* and damage measurement were inconsistent due to low pest populations. Competition from dill was found to reduce yield, but a different planting arrangement could overcome this problem. Remove weeds and plant residue to help reduce egg-laying sites and seedling weeds that nourish small cutworms.

Tilling land before planting, which helps to expose and kill overwintering larvae. Tilling also removes plant residue, which helps to discourage egg laying. Avoid using green manure as this may encourage egg laying, instead use compost. Tilling land in the fall; this helps to destroy or expose overwintering larvae or pupae (Hahn and Burkness, 2015).

2.2.2 Mechanical control

Mechanical control is the use of physical means to reduce the number of insects or insect damage or to exclude pests from the crop field. Mechanical methods include the use of barriers, covers, high pressure water sprays, and hand picking of pests. Barriers come in many shapes and sizes. They prevent the movement of pests onto the plants. Cardboard or plastic cylinders around the base of transplants are an example of a barrier that discourages cutworms and other soil-inhabiting pests from attacking transplants. Cloth or plastic row covers can serve as a cover to keep out pests in a crop field. Screening may increase the temperature of a planting bed, so additional benefits of temperature management may be achieved. Screening is useful for young plants and seedlings that are the most susceptible to pest attack. High pressure water sprays are also a mechanical control method. Sprays are most effective against small, soft-bodied pests like aphids. High pressure water sprays may help remove webbing, dissolve droppings, and quickly reduce the number of pests.

Talekar *et al.* (1986) found that sprinkler irrigation applied to cabbage for five minutes at dusk throughout the life of the crop physically disrupted diamondback moths flying activities and oviposition and drowned larvae and adults. Such a modification of a cultural practice could be a valuable component of a pest management system. The use of lightweight netting row covers, as a barrier against oviposition, is another effective non-chemical insect control technique.

Row covers are mainly used to extend the growing season and by protecting against frosts provide early vegetables by decreasing time to maturity (Mansour, 1989) and they are also effective as barriers against *P. rapae* and *P. xylostella.*

Cutworms can control by placing aluminum foil or cardboard collars around seedlings. This creates a barrier that physically prevents cutworm larvae from feeding on plants. When placing these collars around plants, make sure one end is pushed a few inches into the soil and the other end extends several inches above ground. This should prevent most species of cutworms from getting to plants (Hahn and Burkness, 2015).

2.2.3. Chemical control

For controlling moths, farmers still use organic phosphorus esters. In this group classified active compounds are chlorine pyrifos-methyl, phenitrothion and acephate (Pelosini, 1999). Sufficient efficacy in this relation can attain also with pyrethroids (cypermethrin, deltamethrin, lambda-cyhalothrin, beta-cyfluthrin and tefluthrin). In Slovenia registered products for controlling cabbage moth are from a group of pyrethroids, a product on the basis of pyrethrin, a product which corresponds to oxadiazine and one from the group of insect development inhibitors (IRI). Pyrethroids which are registered in Slovenia are Fastac 10% SC (alfa-cypermethrin) and Karate Zeon 5 CS (lambda-cyhalothrin). Two products are also used when controlling cabbage moth, namely pyrethrin (Spruzit powder) and indoxacarb (Steward). Active ingredient indoxacarb refers to the group of oxadiazines which is also advanced one. Insecticides from the oxadiazines group block Na-channels in nerve fibers. Target insects stop feeding, stay paralyzed and die soon. Product Steward is suitable for integrated production. Chitinase inhibitors display minor danger for human being and are suitable especially for controlling eggs and young larvae (Corvi and Nardi, 1998). Among inhibitors of insect development active ingredients are teflubenzuron, esaflumuron and lufenuron (Pelosini, 1999). The last one is registered in Slovenia and represents an active ingredient of product Match 50 EC.

If there are caterpillars of various developmental stages on the ground, Corvi and Nardi (1998) recommend the application of pyrethroids or carbamates. Both groups of insecticides belong to neurotoxins and act as a contact or stomach insecticides.

In case of cabbage moth control in autumn, Corvi and Nardi (1998) advised double treatment with synthetic insecticides (pyrethroids, carbamates, organic phosphorus esters and growth regulators) and at least spraying with microbiological products on the basis of *Bacillus thuringiensis* var. *kurstaki.* Fenos® (Flubendiamide) and Prevathon® (Chlorantraniliprole) are novel diamide products thus providing growers excellent rotation partners to manage insecticide resistance development in vegetables. These products quickly became very popular among growers since they were very effective against diamondback moth and other lepidopteran larvae (Edralin *et al.,* 2011).

Flubendiamide (Takumi® 20 WDG) is a novel insecticide, representing the IRAC (Insecticide Resistance Action Committee). Mode of Action Group 28 (ryanodine receptor modulator) within the IRAC mode of action classification scheme. Flubendiamide is the first member of phthalic acid diamides, and is active against a broad range of lepidopteran insects (Nauen, 2006; Tohnishi *et al.,* 2005). Chlorantraniliprole (Prevathon® 5%SC) is also a novel insecticide from a new class of chemistry, the IRAC Mode of Action Group 28.

Chlorantraniliprole is the first member of anthranilic diamides, and is potent within the insect order Lepidoptera (Temple *et al*., 2009). Chlorantranilprole is relatively harmless to beneficial arthropods, and has not been found to exhibit cross resistance with existing insecticides (Lahm *et al.,* 2009).Fipronil has been used for control of diamondback moth (DBM), *Plutella xylostella* (L.), on *Brassica* vegetables in Australia since its registration as Regent® 200 SC in 1997 (Ridland and Endersby, 2011).The efficacy of spinetoram against *Plutella xylostella*, *Trichoplusia ni*, *Spodoptera exigua*, *Pieris* spp., and other crucifer pests has been demonstrated in field trials and under conditions of commercial use around the world. It activates certain nicotinic acetylcholine receptors which excites the insect central nervous system, causing paralysis and death of pest insects. Because spinetoram works directly on the insect nervous system, it is fast-acting. Larvae stop feeding and crawling within minutes of first exposure, and death occurs within 24 to 72 hours (Huang *et al.*, 2011).

For controlling cutworms several insecticides are effective. All of them are contact insecticide like Carbaryl, Cyfluthrin, Permethrin etc. But carbaryl shows great result for controlling cutworms in the field condition (Hahn and Burkness, 2015).

2.2.4. Botanical control

Botanical pesticides can be employed as an alternative source to control pests with biodegradable concern, reductive contamination in environment and human health hazards (Devlin and Zettel, 1999; Grainge and Ahmed, 1988). Ahmed (2008) enlisted 2121 plant species, possessing pest control properties which include neem, sweet-flag, cashew, custard apple, sugar apple, derris, lantana, tayanin, Indian privet, agave, crow plant etc. Among these,1005 species of plants having biological properties against insect pests including 384 species as antifeedants, 297 as repellents, 97 as attractants and 31 as growth inhibitors.

Pyrethrin, rotenone and nicotine were among the first compounds from plants used to control agricultural insect pests (Grainge and Ahmed, 1988). Botanical pesticides are also special because they can be produced easily by farmers for sustainable agriculture and small industries (Roy *et al*., 2005). Many plant species are being investigated for their natural products to be used for *P. xylostella* control. For instance, *Azadirachta indica* A. Juss. (Meliaceae), *Melia azedarachta* L. (Meliaceae) and *Acorus calamus* L. (Araceae) treatments were found to inhibit feeding of *P. xylostella* 24 h after treatment (Patil and Goud, 2003). About 413 different species/sub-species of insect pest have been listed by Schmutterer,1995 and found susceptible to neem products. The listed species/sub-species belongs to different insect orders most of them were Lepidoptera (136) and Coleopteran (79). The use of neem-based insecticides as a source of biologically active substances for pest control is increasing worldwide, and have recently gained popularity as components of integrated pest management (Banken and Stark, 1997).

Azadirachtin is the most potent growth regulator and antifeedant (Warthen *et al.,* 1978; Butterworth and Morgan, 1968). The triterpenoid azadirachtin was first isolated from the seeds of the tropical neem tree by Butterworth and Morgan (1968).

Its definite structural formula, which resembles somewhat that of ecdysone (Kraus *et al.* 1985 and Bilton *et al.*1985) (Figure 1).

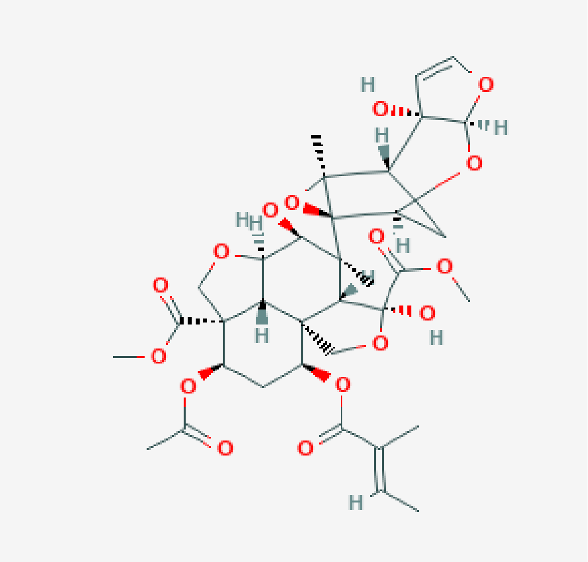


Figure 1. Structural formula of azadirachtin (Butterworth and Morgan,1968)

Azadirachtin is a limonoid allelochemical (Broughton *et al.*,1986; Butterworth and Morgan,1968) present in the fruits and other tissues of the tropical neem tree (*Azadirachta indica*). The fruit is the most important aspect of neem that affects insects in various ways. Crude neem extracts deter settling and reduces feeding in *M. persicae* (Griffiths *et al*. 1989). The females of some lepidopterous insects are repelled by neem treated plant products or other substrates and not laid eggs on them under laboratory conditions. The study conducted to know the biology and the effect of neem (*Azadirachta indica*) oil on the food consumption of lemon butterfly *Papilio demoleus*. The 5th instar larvae consumed the highest amount of lemon leaves.

Among the treatments, 1.5% neem oil showed strong antifeedant effect on food consumption (Karim *et al.*, 2007). Azadirachtin is a potent insect antifeedant. Antifeedancy is the result of effects on deterrent and other chemoreceptors. The antifeedant effects of azadirachtin have been reported for many species of insects. Reduction of feeding also observed after topical application or injection of neem derivatives, including AZA and alcoholic neem seed kernel extract. This means that the reduction of food intake by insects is not only gustatory which means that sensory organs of the mouth part also non-gustatory regulate it. These two phagodeterrent/antifeedant effects were called primary and secondary (Schmutterer, 1985). Azadirachtin has different influence on the metamorphosis of the insects resulting in various morphogenetic defects as well as mortality, depending on the concentration applied.

The IGR effect of neem derivatives such as methanolic neem leaf extract and azadirachtin in larvae and nymphs of insects was first observed in 1972 in Heteroptera (Leuschner, 1972) and Lepidoptera. Molting (if it occurred) was incomplete and resulted in the death of the tested insects. Botanicals possess an array of properties including insecticidal activity and insect growth regulatory activity against many insect pests and mites (Rajasekaran and Kumaraswami,1985; Prakash *et al*., 1987 and 1990). Repellent activity of neem against oviposition by Lepidopterous pests has also been reported for *Spodoptera litura* (Joshi and Sitaramaiah, 1979), *Cnaphalocrocis medinalis* (Saxena *et al*., 1981) and *Earies vittella* (Sojitra and Patel, 1992). Extracts of neem and bakain caused maximum adverse effects on fecundity and hatching.

Lakshmanan (2001) reported effectiveness of neem extract alone or in combination with other plant extracts in managing lepidopteran pest's viz., *E. vittella*, *Chilo partellus* Swinhoe, *Helicoverpa armigera* and *S. litura*. Maximum reduction (65.7%) in bollworm infestation was observed in garlic treated plot. Garlic extract and NSKE both at 10% were found to be superior. Lowest bollworm incidence was observed with NSKE (10.3%), datura and neem oil emulsion (Anonymous, 1987). Sardhana and Krishna Kumar (1989) studied the efficacy of neem oil, karanj oil (both at 0.5,1.0 and 2.0%) and garlic oil (0.25, 0.5 and 1.0%) in comparison with monocrotophos (0.05%). Among the oils, neem oil and karanj oil offered effective control against okra fruit borers. It was concluded that weekly application of neem oil at two per cent concentration was effective in controlling fruit borer in okra and found safe to natural enemies.

Analysis of *Thuja occidentalis* L. essential oil used for insect fumigation by phase gas chromatography revealed the presence of 22 compounds including α-thujone (49.64%), fenchone (14.06%), and β-thujone (8.98%) (Joshy *et al.*, 2020).

When insects treated with aromatized powder, significant differences were also found between treatments and control. Germination of cowpea seeds not significantly affected by the treatments. Five days after sowing, germination was 88, 97 and 97%, respectively, when cowpea grains were treated and exposed, treated and unexposed, untreated and unexposed, respectively, while those untreated and exposed had 15% germination (Keita, *et al.*, 2001).

CHAPTER III

MATERIALS AND METHODS

The present study regarding effectiveness of botanicals in controlling major Lepidopteran insect pests of summer cabbage particularly cabbage semi-looper (*Trichoplusia ni*), diamondback moth (*Plutella xylostella*) and tobacco caterpillar/prodenia caterpillar (*Spodoptera litura*) has been conducted during May 2018 to September 2018 in the experimental fields of Sher-e- Bangla Agricultural University, Dhaka. Required materials and methodology are described below under the following sub-headings:

3.1 Location of the experimental field

The experiment was carried out in the central Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh and which is situated in 23º74´´N latitude and 90º35´´E longitude and an elevation of 8.2 m from sea level (Anon., 1989) and has been presented in Appendix I.

3.2 Climate of the experimental area

The climate of experimental site is subtropical, characterized by three distinct seasons, the winter season from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October (Edris *et al*., 1979). The average maximum and minimum temperature were 32.9ºC and 24.5º C respectively, during the experimental period (Apendix-II). The country summer season is characterized by plenty of rainfall and cloudy weather. Meteorological data which are related to the temperature, relative humidity and rainfall during the experimental period was collected from Bangladesh Meteorological Department (Climate Division), Sher-e-Bangla Nagar and has been presented in Appendix II.

3.3 Soil of the experimental field

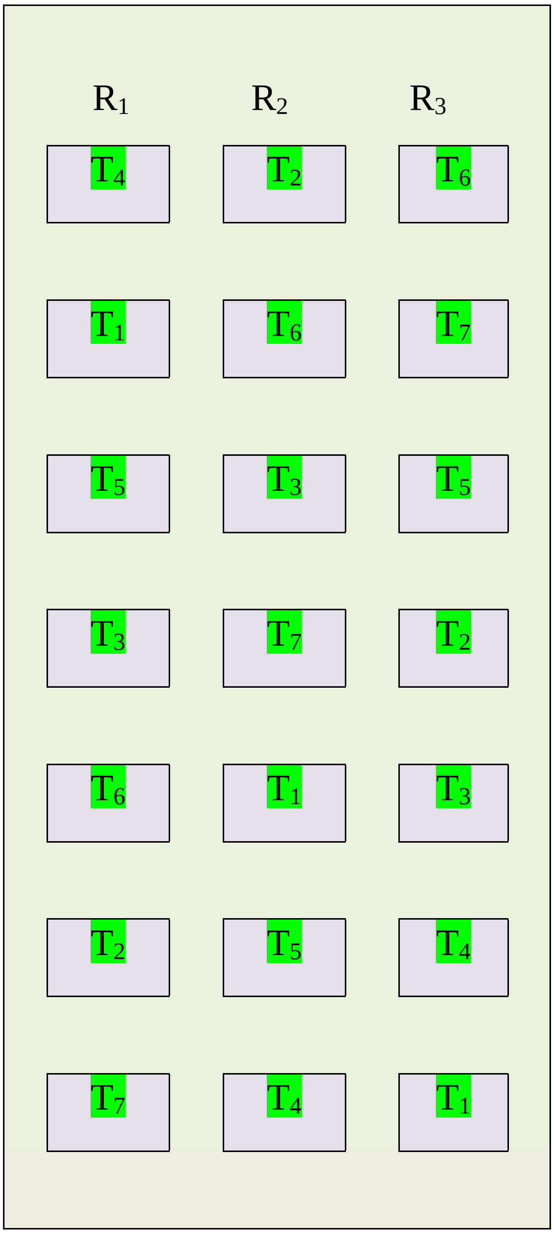
The soil of the experimental area belongs to the Modhupur Tract (UNDP, 1988) corresponding AEZ No. 28 and is shallow red brown terrace soil. The land of the selected experimental plot is medium high under the Tejgaon series (FAO, 1988). The characteristics of the soil under the experimental plot were analyzed in the Soil Testing Laboratory, SRDI, Dhaka and has been represented in Appendix III.

3.4 Planting material

The test crop used in the experiment was cabbage variety Tropical-33. It is an imported high yielding variety with average yield of 40-50 tha^{-1}. The seeds were collected from Advanced Chemical Industries (ACI) limited, Tejgaon, Dhaka.

3.5 Experimental Design and Layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The field with good tilth was divided into 3 blocks. The layout of the experiment was prepared for distributing all of the treatments randomly. Each experiment consisted of total 21 plots of size 2.5 m × 1.6 m. The layout of the experiment is shown in Figure 2.



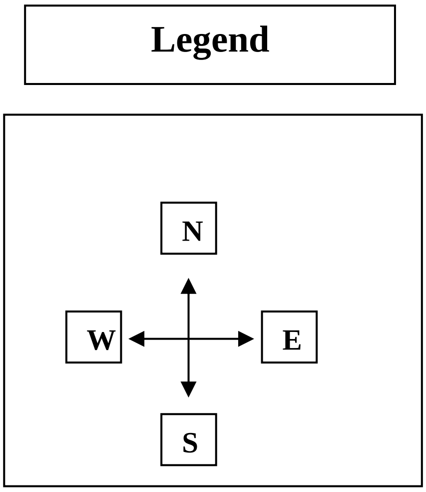


Figure 2. Layout of the experimental plot.

Plate 1. Experimental research field of cabbage during the study period.

3.6 Land preparation

The selected plot of the experiment was opened in the 1st week of June 2018 with a power tiller and left exposed to the sun for a week. Subsequently cross ploughing was done several times with a country plough followed by harrowing and laddering to make the land suitable for growth of cabbage seedlings. All weeds, stubbles and residues were eliminated from the experimental field. Finally, a good tilth was obtained for proper growth and development of cabbage. The Field layout was done according to the design, after land preparation. The plots were raised by 10cm from the soil surface keeping the drain around the plots (Plate 1).

3.7 Manuring and fertilization

Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MoP) were used as a source of nitrogen, phosphorous, and potassium, respectively. Manures and fertilizers were applied according to the recommended fertilizer doses for cabbage production per hectare by BARC (2012) (Table-1).

Table 1. Dose and method of application of fertilizers in cabbage field.

Fertilizers and Manures	Dose/ha	Application (%)		
		Basal	15 DAT	35 DAT
Cowdung	5 ton	100	---	---
Urea	370 kg	--	50	50
TSP	250 kg	100	---	---
MoP	250 kg		50	50

The total amount of cow-dung and TSP was applied as basal dose at the time of land preparation. The total amount of Urea and MoP was applied in two equal installments at 15 and 35 days after transplanting (DAT) as ring method under moist soil condition and mixed thoroughly with the soil as soon as possible for better utilization.

3.8 Raising of seedlings

The seedlings were raised in 3 m × 1 m size seed bed under special care at central farm. The soil of the seed bed was well ploughed with a spade and prepared into loose friable dried masses and to obtain good tilth to provide a favorable condition for the vigorous growth of young seedlings. Weeds, stubbles and dead roots of the previous crop were removed. The seed bed was dried in the sun to destroy the soil insect and protect the young seedlings from the attack of damping off disease. To control damping off disease Cupravit fungicide were applied. Decomposed cow dung was applied in prepared seed bed @10 tha^{-1}. Ten (10) grams of seeds were sown in seedbed on May 11, 2018. Before sowing the cabbage, seeds were soaked for half an hour in water for rapid and uniform germination. After sowing, the seeds were covered with fine light soil.

At the end, germination shading was done by bamboo mat “chatai” over the seed bed to protect the young seedlings from scorching sunshine and heavy rainfall. Light watering, weeding was done as and when necessary to provide seedlings with an ideal condition for its growth (Plate 2).

Plate 2. Cabbage seedlings in the seedbed.

3.9 Transplanting

Healthy and uniform seedlings of 30 days old were transplanted in the experimental plots on 11 June, 2018. The seedlings were transferred carefully from the seed bed to experimental plots to avoid damage to the root system. To minimize the damage to the roots of seedlings, the seed beds were watered one hour before uprooting the seedlings. Transplanting was done in the afternoon. The seedlings were watered immediately after transplanting. There were 5 seedlings in each row and a total of 10 seedlings were transplanted in each plot. Seedlings were transplanted in the plot with distance between row to row was 60 cm and plant to plant was 45 cm. The young transplanted seedlings were provided shade by banana leaf sheath during day to protect them from scorching sunshine and continued up to 7 days until they were set in the soil. Plants were kept open at night to allow them receiving dew. A number of seedlings were also planted in the border of the experimental plots for gap filling.

3.10 Intercultural operations

After transplanting seedlings, various intercultural operations such as gap filling, weeding, earthing up, irrigation etc. were accomplished for better growth and development of the cabbage.

3.10.1 Gap filling

The transplanted seedlings in the experimental plot were kept under careful observation. Very few seedlings were damaged after transplanting and were replaced by new ones from the stock. Replacement was done with healthy seedling having a boll of earth planted on the same date collected from the side of the unit plot. The transplanted seedlings were provided shading and watering for 7 days for their proper development.

3.10.2 Weeding

The land of each plot was kept free from weeds by weeding four times. The first weeding was done after 15 days of transplanting and the remaining weeding was done after 30, 45 and 60 days of transplanting.

3.10.3 Irrigation

Light watering was given by a watering can at every morning and afternoon after transplanting. Following transplanting, watering was continued for a week for rapid growth and well establishment of the transplanted seedlings. As it was rainy season, regular irrigation was not needed. Beside this, a routine irrigation was given when necessary.

3.10.4 Earthing up

Earthing up was done at 20 and 40 days after transplanting on both sides of rows by taking the soil from the space between the rows by a small spade.

3.11 Treatments used for management

The experiment was evaluated to determine the efficacy of different botanical products against major Lepidopteran insect pests of summer cabbage. The botanical based treatments as well as their doses used in the study are given bellow: -

T_1 = Spraying of Mahogany seed kernel extract@ 3.0 ml/L of water

T_2 = Spraying of Tobacco leaf extract @ 3.0 ml/L of water

T_3 = Spraying of Garlic extract @ 3.0 ml/L of water

T_4 = Spraying of Neem leaf extract @ 3.0 ml/L of water

T_5 = Spraying of Neem seed kernel extract @ 3.0 ml/L of water

T_6 = Spraying of Neem oil @ 3.0 ml/L of water

T_7 = Untreated control.

3.12 Treatment preparation

3.12.1 Neem leaf extract

The fresh neem leaves were collected from the neem tree from the Horticulture Garden of SAU. Leaves were sun dried 2 to 3 days and crashed using electric grinder, of which 250 gm dried neem leaf powder was taken into a 500 ml beaker. 250 ml water was poured into the beaker and then the beaker was shaken for 30 minutes with the magnetic stirrer to make the extracts of neem leaves. The aqueous extract then filtered using Whatman no. 1 paper filter and preserved the aqueous extract as flock solution in the refrigerator at 4^0c for experimental use.

3.12.2 Neem seed kernel extract

The mature and dried neem seeds were collected from the neem tree found in the Horticulture Garden of SAU. Then seeds were roasted at 60ºC to 80ºC for 1 to 2 days by electric oven. The seed kernel was separated and taken into the electric blender for blending. Then 250 gm of this powder was taken into a beaker and 250 ml water was added into it. The beaker was shaken by electric stirrer for 30 minutes thoroughly the mixture. The aqueous mixture then filtered using Whatman no. 1 paper filter and preserved the aqueous extracts in the refrigerator at 4^0c for future experimental use.

3.12.3 Neem oil

The fresh neem oil was collected from Chawkbazar, Dhaka and the trix liquid detergent was collected from the local market of Agargoan bazar, Dhaka. All sprays were made according to the methods described earlier. For each neem oil application, 15 ml neem oil (@ 3.0 ml/L of water i.e. 0.3% per 5 liters of water was used. The mixture within the spray machine (knapsack sprayer) was shacked well and sprayed on the upper and lower surface of the plants until the drop run off from the plant. Three liters spray material was required to spray in three plots at each replication.

3.12.4 Garlic extract

Fresh garlic bulbs were collected from the local market and chopped the bulbs in small size by sharp knife. Then 250 gm chopped garlic bulbs were taken into electric blender for blending. Then the blended garlic was taken into the beaker and 250 ml water was added with the garlic extract. The beaker was shaken for 30 minutes with the magnetic stirrer to make the extracts of garlic. The aqueous extract then filtered using Whatman no.1 paper filter and preserved the aqueous extracts of garlic in the refrigerator at 4^0c for experimental use.

3.12.5 Mahogany seed kernel

The mature and dried mahogany seeds were collected from the mahogany tree found in the campus of SAU. Then seeds were roasted at 60ºC to 80ºC for 1 to 2 days by electric oven. The seed kernel was then separated and taken into the electric blender for blending. Then 250 gm of this powder was taken into a beaker and 250 ml water was added into it. The mixture in the beaker was then shaken by electric stirrer for 30 minutes thoroughly the mixture. The aqueous mixture then filtered using Whatman no. 1 paper filter and preserved the aqueous extracts in the refrigerator at 4^0c for future experimental use.

3.12.6 Tobacco leaf extract

The fresh tobacco leaves were collected from the local market. Leaves were crashed using electric grinder, of which 250 gm dried tobacco leaf powder was taken into a 500 ml beaker. After that 250 ml water was added into the beaker and then the beaker was shaken for 30 minutes with the magnetic stirrer to make the extracts of tobacco leaves. The aqueous extract then filtered using Whatman no. 1 paper filter and preserved the aqueous extract as flock solution in the refrigerator at 4^0c for experimental use.

3.13 Treatments application

T_1: Mahogany seed kernel extract @ 3.0 ml/L of water was sprayed at 7 days interval. Under this treatment, mahogany seed kernel extract was applied @ 15 ml /5L of water. After proper shaking, the prepared spray was applied with knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_2: Tobacco leaf extract @ 3.0 ml/L of water was sprayed at 7 days interval. Under this treatment, tobacco leaf extract was applied @ 15 ml /5L of water. After proper shaking, the prepared spray was applied with knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_3: Garlic extract @ 3.0 ml/L of water was sprayed at 7 days interval. Under this treatment, garlic extract was applied @ 15 ml /5L of water. After proper shaking, the prepared spray was applied with knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_4: Neem leaf extract @ 3.0 ml/L of water was sprayed at 7 days interval. Under this treatment, neem leaf extract was applied @ 15 ml /5L of water. After proper shaking, the prepared spray was applied with knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_5: Neem seed kernel extract @ 3.0 ml/L of water was sprayed at 7 days. Under this treatment, neem seed kernel extract was applied @ 15 ml /5L of water. After proper shaking, the prepared spray was applied with knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_6: Neem oil @ 3.0 ml/L of water was sprayed at 7 days interval. Under this treatment, neem oil was applied @ 15 ml /5L of water mixed with trix liquid detergent @ 10 ml (1%) to make the oil easy soluble in water. After proper shaking, the prepared spray was applied with knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_7: Untreated control treatment. There was no any control measure applied in cabbage field.

3.14 Data collection

For data collection five plants per plot were randomly selected and tagged. The cabbage plants were closely examined at regular intervals commencing from 20 days after transplanting (DAT) to harvesting of cabbage head. Infestation by different major insects were recorded at 20, 30, 40, 50 and 60 DAT. The data were recorded on number of cabbage semi-looper, diamondback moth larvae, tobacco caterpillar, infested leaves. The following parameters were considered during data collection:

3.14.1 Counting of insect pests of cabbage and infested leaves

Data were collected on the number of cabbage semi-looper, tobacco caterpillar and diamondback moth larvae and number of infested leaves caused by cabbage semi-looper, tobacco caterpillar and diamondback moth larvae from randomly selected 5 tagged plants per plot and counted separately for each treatment.

3.14.2 Number, weight of healthy and infested cabbage head

Data were collected on the number of healthy and infested cabbage head per plot which was harvested at fully mature head (upto 15th September) stage of cabbage and weighed separately for each treatment.

Data of the yield attributing characters of cabbage like diameter of head, height/thickness of head, weight of head and yield (ton ha^{-1}) was also recorded after harvesting.

3.15 Level of infestation

The number of insects, uninfested and infested leaves and plants of cabbage caused by major insects were counted. The observations were recorded at the first observation of no. of insect's larvae, infested leaves and plants and were continued up to harvesting stage of the cabbage at 10 days of interval. The data on the yield was also recorded. The level of leaf and plant infestations per plant and plot, respectively was then calculated using the following formula:

$$\% \text{ leaf or plant infestation} = \frac{\text{No. of infested leaves or plants}}{\text{Total no. of leaves or plants}} \times 100$$

3.16 Insect infestation percentage on head

Insects infestation (%) on heads were calculated at vegetative and harvesting stages using the following formulae:

$$\% \text{ head infestation by number} = \frac{\text{Number of infested heads}}{\text{Total number of heads}} \times 100$$

$$\% \text{ head infestation by weight} = \frac{\text{Weight of infested head}}{\text{Total head weight}} \times 100$$

3.17 Yield

Yield plot^{-1} was recorded from the field and then it was converted to total yield (t ha^{-1}). Percent increase or decrease of yield over control was calculated by using the following formula:

Percent increase of yield over control

$$= \frac{\text{Yield of treated plots - Yield of control plots}}{\text{Yield of control plots}} \times 100$$

Percent decrease of yield over control

$$= \frac{\text{Yield of control plots - Yield of treated plots}}{\text{Yield of control plot}} \times 100$$

3.18 Harvesting

Harvesting of the cabbage was not possible on a certain or particular date because the initiation of head as well as attaining the head at marketable size in different plants were not uniform. Only the compact marketable heads were harvested with fleshy stalk by using sharp knife. Before harvesting of the cabbage head, compactness of the head was tested by pressing with thumbs.

3.19 Statistical analysis

The data collected on different parameters were compiled and tabulated for statistical analysis. Statistical analysis was done using the Statistix 10 computer package program. Mean values were ranked and compared by Least Significant Difference (LSD) test at 5% level of significance (Fisher, 1935).

CHAPTER IV

RESULTS AND DISCUSSIONS

The study was conducted to evaluate the effectiveness of some botanicals for controlling major Lepidopteran insect pests of summer cabbage in the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period from May, 2018 to September, 2018. The analysis of variance (ANOVA) of the data on cabbage leaf and head infestation and different yield contributing characters of cabbage are given in Appendix. The results have been presented and discussed, and possible interpretations have been given under the following sub-headings:

4.1. Leaf infestation of cabbage

4.1.1. Leaf infestation by cabbage semi-looper

Significant variations ($p>0.05$) were observed among treatments (Table 2) of different management practices in terms of leaf infestation by cabbage semi-looper (Plate 3) at different days after transplanting (DAT). At 20 DAT, the highest leaf infestation was recorded in untreated control plot (T_7) (10.67 leaves/5 plants) which was statistically different from all other treatments followed by T_1 (9.33 leaves/5 plants) and T_3 (8.33 leaves/5 plants). On the other hand, the lowest leaf infestation was recorded in T_6 (4.77 leaves/5 plants) which was statistically similar with T_4 (5.33 leaves /5 plants) followed by T_5 (6.67 leaves /5 plants) and T_2 (7.33 leaves /5 plants) (Table 2).

At 30 DAT, the highest leaf infestation was recorded again in T_7 (11.00 leaves/5 plants) which was statistically similar to that of T_1 (10.33 leaves /5 plants) but significantly different from all other treatments followed by T_3 (9.33 leaves /5 plants) and T_2 (8.33 leaves /5 plants). On the other hand, the lowest leaf infestation was recorded in T_6 (5.50 leaves/5 plants) which was statistically similar to T_4 (6.33 leaves /5 plants) followed by T_5 (7.33 leaves /5 plants). More or less similar trends of leaf infestation by number were also recorded at 40 DAT, 50 DAT and 60 DAT (Table 2).

In case of mean infestation, the highest number of leaf infestation was recorded in untreated control plot (T_7) (11.80 leaves/5 plants) which was significantly different from all other treatments followed by T_1(8.93 leaves/5 plants) and T_3 (7.90 leaves/5 plants). On the other hand, the lowest infestation was recorded in T_6 (4.79 leaves/5 plants) which was statistically different from all other treatments followed by T_4 (5.46 leaves/5 plants) and T_5 (6.17 leaves/5 plants) (Table 2).

Considering the percent reduction of leaf infestation, the highest reduction over control was achieved in T_6 (59.40%) followed by T_4 (53.73%) and T_5 (47.71%). Nevertheless, the minimum reduction of leaf infestation over control was found in T_1 (24.32%) followed by T_3 (33.05%) (Table 2). More or less similar result was found by Iqbal *et al.* (2015). They obtained 64.62% infestation reduction over control by applying neem derivatives against cabbage semi-looper. Botanicals including neem-based insecticides play important roles in crop protection. They act as a feeding deterrent, repellent, and growth regulators against several insect pests leading to their death (Joshy *et al.*, 2020).

Potential efficacy of neem-based extracts has been revealed by several studies against different lepidopterous insects e.g. cabbage looper (*Trichoplusia ni* Hub.), diamondback moth larvae (*Plutella xylostella* L.) (Akhtar *et al*., 2008). It was demonstrated by many studies that aqueous solution of tobacco extract could successfully control major lepidopterous insects of different vegetables, and even at 1.25%, parasites of livestock could be controlled by it (Olivo *et al*., 2009), at the concentration of 2-6%, effective result was found against stored grain insect pests (Sarmamy *et al*., 2011). One of the reasons of this effectiveness of botanicals against several insect pests would be their crude and raw nature rather than pure extractives such as essential oils (Gulzar *et al*., 2017).

Table 2. Infestation of cabbage caused by semi-looper at different days after transplanting (DAT) of cabbage.

Treatments	Number of infested leaves per five plants					Mean	% reduction over control
	20 DAT	30 DAT	40 DAT	50 DAT	60 DAT		
T_1	9.33 b	10.33 a	9.33 b	8.33 b	7.33 b	8.93 b	24.32
T_2	7.33 d	8.33 c	7.33 d	6.33 d	5.50 d	6.97 d	40.93
T_3	8.33 c	9.33 b	8.33 c	7.33 c	6.17 c	7.90 c	33.05
T_4	5.33 e	6.33 e	5.67 ef	5.17 e	4.80 e	5.46 f	53.73
T_5	6.67 d	7.33 d	6.33 e	5.42 e	5.10 de	6.17 e	47.71
T_6	4.77 e	5.50 e	5.17 f	4.67 e	3.87 f	4.79 g	59.40
T_7	10.67 a	11.00 a	11.67 a	13.00 a	12.67 a	11.80 a	-
LSD $_{(0.05)}$	0.88	0.94	0.75	0.83	0.53	0.64	-
CV%	6.57	6.39	5.49	6.49	4.57	4.85	-

[DAT= Days after transplanting, in a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

From the Table 2 it is observed that among the different treatments, T_6 performed the best in reducing the leaf infestation of cabbage (59.40%) by number due to attack of cabbage semi-looper than the other treatments, whereas, T_1 showed the least performance results in reducing the leaf infestation of cabbage (24.32%) by number over control. As a result, the order of rank of efficacy among the different treatments including one untreated control in terms of percent leaf infestation by semi-looper on cabbage by number was $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

4.1.2 Leaf infestation by tobacco caterpillar

Significant variations ($p>0.05$) were observed among different treatments (Table 3) for different management practices in terms of leaf infestation by tobacco caterpillar (Plate 3) at different days after transplanting (DAT). At 20 DAT, the highest leaf infestation was recorded in T_7 (14.33 leaves/5 plants) which was statistically different from all other treatments followed by T_1 (11.67 leaves/5 plants) and T_3 (11.33 leaves/5 plants). On the other hand, the lowest leaf infestation was recorded in T_6 (7.33 leaves/5 plants) which was statistically different from all other treatments followed by T_4 (9.33 leaves /5 plants), T_5 (10.33 leaves /5 plants) and T_2 (10.67 leaves /5 plants).

At 30 DAT, the highest leaf infestation was recorded in T_7 (15.33 leaves/5 plants) which was statistically different from all other treatments followed by T_1 (11.33 leaves /5 plants) and T_3 (10.67 leaves /5 plants). On the other hand, the lowest leaf infestation was recorded in T_6 (6.33 leaves/5 plants) which was statistically different from all other treatments followed by T_4 (8.33 leaves /5 plants), T_5 (9.33 leaves /5 plants) and T_2 (10.00 leaves /5 plants). More or less similar trends of leaf infestation by number were also recorded at 40 DAT, 50 DAT and 60 DAT (Table 3).

In case of mean infestation, the highest number of leaf infestation was recorded in T_7 (16.33 leaves/5 plants) which was statistically different from all other treatments followed by T_1(11.27 leaves/5 plants) and T_3 (10.80 leaves/5 plants). On the other hand, the lowest infestation was recorded in T_6 (6.25 leaves/5 plants) which was statistically different from all other treatments followed by T_4 (8.07 leaves/5 plants) and T_5 (9.13 leaves/5 plants) and T_2 (9.80 leaves/5 plants) (Table 3).

Considering the percent reduction of leaf infestation over control, the highest 61.73% reduction over control was achieved in T_6 followed by T_4 (50.58%) and T_5 (44.09%). On the other hand, the minimum reduction of leaf infestation over control was found in T_1 (30.99%) which was very close to T_3 (33.86%) (Table 3). This result was supported by Reddy *et al.* (2017) where they found 45.04% and 68.00% infestation reduction of tobacco caterpillar (*Spodoptera litura* Fab.) by applying azadirachtin (0.03%) at 7 DAS (Days After Spraying) and 10 DAS, respectively. Amtul (2014) found neem (*Azadirachta indica*) derived compounds as inhibitors of digestive alpha-amylase in insect pests. This inhibition can cause digestive problems in insects in addition to their death.

From these above findings it was revealed that among the different treatments, T_6 showed the best result in reducing the leaf infestation of cabbage (61.73%) by number due to attack of tobacco caterpillar than the other treatments, whereas, T_1 showed the least performance in reducing the leaf infestation of cabbage (30.99%) by number over control. As a result, the order of rank of efficacy among the different treatments including untreated control in terms of percent leaf infestation of cabbage by number was $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

Neem-based insecticides act as feeding deterrent against a number of insect pests. The level of the ecdysone hormone is reduced by disrupting the molting process leading the larvae incapable to become adults. The immature larvae died remaining as immature stage for a longer period. Direct contact of the spray may kill the larvae of some soft skinned insects. Although adults are not killed by the growth regulating properties of neem-based insecticides, their mating and sexual behavior is disrupted leading to the reduced fecundity (Joshy *et al.*, 2020).

Table 3. Infestation of cabbage caused by tobacco caterpillar at different days after transplanting (DAT) of cabbage.

Treatments	Number of infested leaves per five plants					Mean	% reduction over control
	20 DAT	30 DAT	40 DAT	50 DAT	60 DAT		
T_1	11.67 b	11.33 b	12.33 b	11.00 b	10.00 b	11.27 b	30.99
T_2	10.67 cd	10.00 cd	10.67 cd	9.33 c	8.33 c	9.80 c	39.99
T_3	11.33 bc	10.67 bc	11.67 bc	10.67 b	9.67 b	10.80 b	33.86
T_4	9.33 e	8.33 e	8.67 e	7.67 d	6.33 d	8.07 d	50.58
T_5	10.33 d	9.33 de	9.67 de	8.67 c	7.67 c	9.13 c	44.09
T_6	7.33 f	6.33 f	6.67 f	5.67 e	5.27 d	6.25 e	61.73
T_7	14.33 a	15.33 a	16.00 a	17.00 a	19.00 a	16.33 a	-
LSD $_{(0.05)}$	0.96	1.19	1.15	0.98	1.33	0.73	-
CV%	5.06	6.54	6.00	5.49	7.87	4.02	-

[DAT= Days after transplanting, in a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

4.1.3 Leaf infestation by diamondback moth larvae

Significant variations ($p>0.05$) were observed among different treatments (Table 4) for using different management practices in terms of leaf infestation by Diamondback moth larvae (Plate 3) at different days after transplanting (DAT). At 20 DAT, the highest leaf infestation was recorded in T_7 (10.67 leaves/5 plants) which was statistically different from all other treatments followed by T_1 (9.67 leaves/5 plants) and T_3 (8.67 leaves/5 plants). On the other hand, the lowest leaf infestation was recorded in T_6 (4.43 leaves/5 plants) which was statistically different from all other treatments followed by T_4 (5.50 leaves /5 plants), T_5 (6.67 leaves /5 plants) and T_2 (7.67 leaves /5 plants) (Table 4).

At 30 DAT, the highest leaf infestation was recorded in T_7 (13.00 leaves/5 plants) which was statistically different from all other treatments followed by T_1 (10.67 leaves /5 plants) and T_3 (9.67 leaves /5 plants). On the other hand, the lowest leaf infestation was recorded in T_6 (4.83 leaves/5 plants) which was statistically similar to that of T_4 (5.50 leaves /5 plants) but different from all other treatments and followed by T_5 (6.33 leaves /5 plants) and T_2 (8.33 leaves /5 plants). More or less similar trends of leaf infestation by number were also recorded at 40 DAT, 50 DAT and 60 DAT (Table 4).

In case of mean infestation, the highest number of leaf infestation was recorded in T_7 (13.73 leaves/5 plants) which was significantly different from all other treatments followed by T_1 (9.07 leaves/5 plants) and T_3 (8.27 leaves/5 plants). On the other hand, the lowest infestation was recorded in T_6 (4.39 leaves/5 plants) which was statistically similar with T_4 (5.07 leaves /5 plants) but different from all other treatments and followed by T_5 (5.77 leaves /5 plants) and T_2 (7.03 leaves /5 plants).

Considering the percent reduction of leaf infestation over control, the highest reduction over control was achieved in T_6 (68.03%) followed by T_4 (63.07%) and T_5 (57.98%). On the other hand, the minimum reduction of leaf infestation over control was found in T_1 (33.94%) followed by T_3 (39.77%) (Table 4). This result agreed with Dey *at el.* (2017). They reported that, 70-74 % larval mortality of diamondback moth can be obtained by applying neem-based insecticides.

From these above findings it was revealed that among the different treatments, T_6 showed the best result in reducing the leaf infestation of cabbage (63.03%) by number due to attack of Diamondback moth larvae than the other treatments; whereas, T_1 showed the least performance in reducing the leaf infestation of cabbage (33.94%) by number over control. As a result, the order of rank of efficacy among the different treatments including one untreated control in terms of percent leaf infestation of cabbage by number was $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

Botanicals possess properties like repellency, ant-feeding, quick knockdown, and flushing action. Indeed, consumption of neem extract-treated leaves affected the development of the 4th stage larva of diamondback moth and reduced the larval population by causing death (Mochiah *et al.,* 2011).

The oviposition of *Plutella xylostella* occurs through olfactory and gustatory stimuli and also through the chemoreceptors in the ovipositor, tarsus, or mouth. The secondary metabolites present in different plant extracts act to reduce the oviposition stimuli of diamondback moth (Feng *et al.,* 2017). Charleston *et al.* (2006) reported that neem leaf extracts have deterrent effects on *Plutella xylostella* oviposition.

Table 4. Infestation of cabbage caused by diamondback moth larvae at different days after transplanting (DAT) of cabbage.

Treatments	Number of infested leaves per five plants					Mean	% reduction over control
	20 DAT	30 DAT	40 DAT	50 DAT	60 DAT		
T_1	9.67 b	10.67 b	9.33 b	8.33 b	7.33 b	9.07 b	33.94
T_2	7.67 d	8.33 c	7.33 c	6.33 c	5.50 c	7.03 d	48.79
T_3	8.67 c	9.67 b	8.67 b	7.67 b	6.67 b	8.27 c	39.77
T_4	5.50 f	5.50 de	5.27 de	4.83 de	4.27 de	5.07 ef	63.07
T_5	6.67 e	6.33 d	5.87 d	5.27 d	4.73 cd	5.77 e	57.98
T_6	4.43 g	4.83 e	4.60 e	4.30 e	3.80 e	4.39 f	68.03
T_7	10.67 a	13.00 a	14.00 a	15.33	15.67 a	13.73 a	-
LSD $_{(0.05)}$	0.77	1.17	1.15	0.86	0.83	0.78	-
CV%	5.7	7.88	8.24	6.51	6.81	5.74	-

[DAT= Days after transplanting, in a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

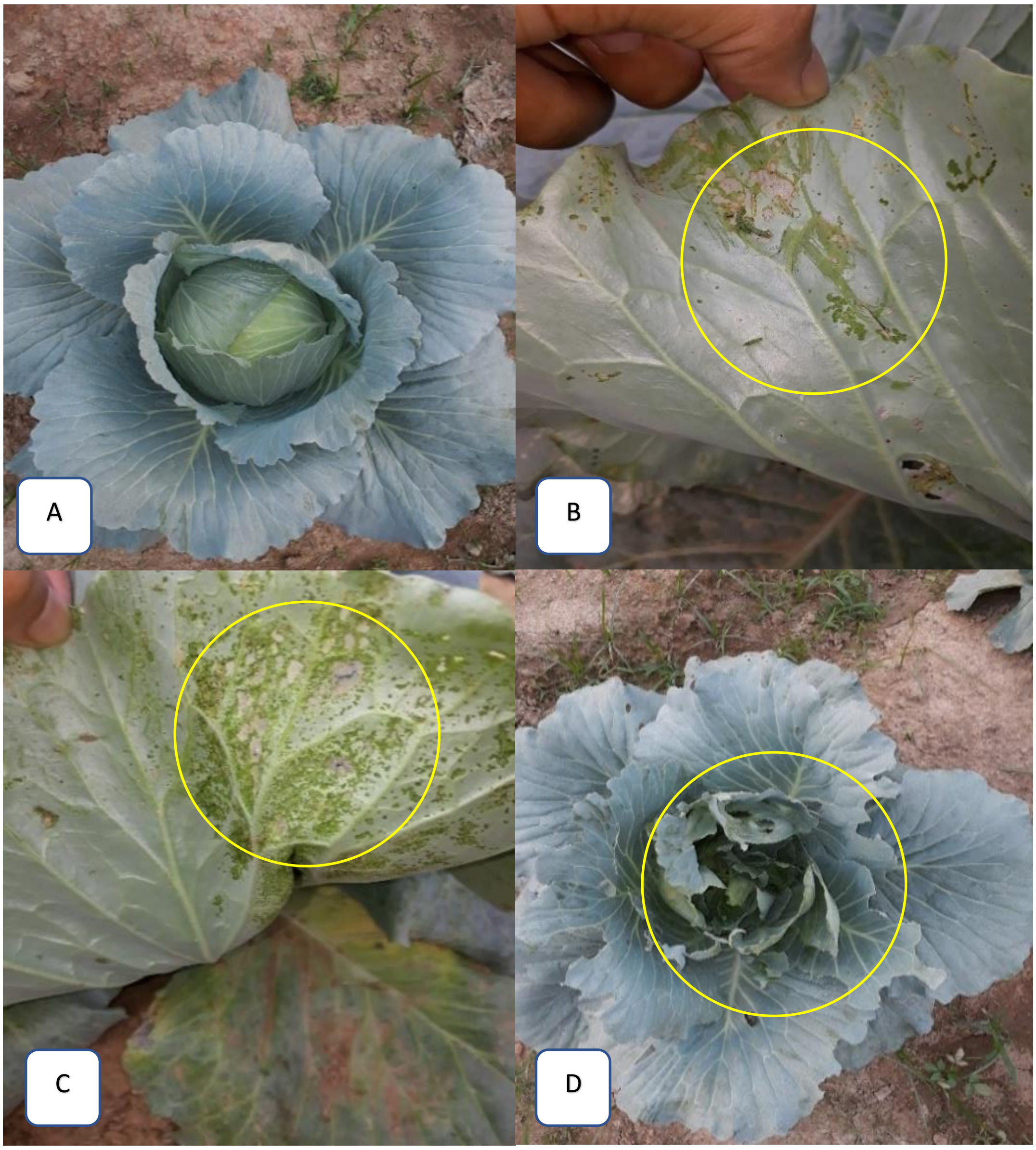


Plate 3. A) Healthy cabbage head, B) Infested by semi looper, C) Infested by Tobacco caterpillar, D) Infested by diamondback moth larvae.

4.2 Incidence of insect pest population

4.2.1 Incidence of cabbage semi-looper

Significant variations ($p>0.05$) were observed among different treatments used for the management practices in terms of number of cabbage semi-looper larvae (Plate 4) at different days after transplanting (DAT). At 20 DAT, the highest number of cabbage semi-looper larvae per five plants was recorded in T_7 (13.67 larvae/5 plants) which was statistically different from all other treatments followed by T_1 (13.00 larvae/5 plants) and T_3 (12.33 larvae/5 plants). On the other hand, the lowest number of cabbage semi-looper larvae per five plants was recorded in T_6 (7.33 larvae/5 plants) which was statistically different from all other treatments followed by T_5 (8.67 larvae/5 plants), T_4 (9.33 larvae/5 plants) and T_2 (10.33 larvae/5 plants) (Table 5).

At 30 DAT, the highest number of cabbage semi-looper larvae per five plants was recorded in T_7 (15.00 larvae/5 plants) which was statistically different from all other treatments followed by T_1 (12.00 larvae/5 plants) and T_3 (11.33 larvae/5 plants). On the other hand, the lowest number of cabbage semi-looper larvae per five plants was recorded in T_6 (6.33 larvae/5 plants) which was statistically different from all other treatments followed by T_5 (9.67 larvae/5 plants), T_4 (10.33 larvae/5 plants) and T_2 (11.33 larvae/5 plants) (Table 5). More or less similar trends of number of cabbage semi-looper per five plants were also recorded at 40 DAT, 50 DAT and 60 DAT (Table 5).

In case of mean number of cabbage semi-looper larvae, the highest number of cabbage semi-looper larvae was recorded in T_7 (15.67 larvae/5 plants) which was significantly different from all other treatments followed by T_1 (10.21 larvae/5 plants) and T_3 (9.81 larvae /5 plants). On the other hand, the lowest number of cabbage semi-looper larvae was recorded in T_6 (5.47 larvae/5 plants) which was statistically different from all other treatments followed by T_5 (7.33 larvae/5 plants), T_4 (8.09 larvae/5 plants) and T_2 (8.92 larvae/5 plants) (Table 5).

Considering the percent reduction of number of cabbage semi-looper larvae among different management practices over control, the highest reduction over control was achieved in T_6 (65.09%) followed by T_5 (53.22%) and T_4 (48.37%). On the other hand, the minimum reduction of number of cabbage semi-looper larvae over control was found in T_1 (34.84%) followed by T_3 (37.39%) (Table 5). This result was supported by Iqbal *et al.* (2015). They obtained 64.62% infestation reduction over control by applying neem derivatives against cabbage semi-looper. Amtul (2014) reported neem (*Azadirachta indica*) derived compounds as inhibitors of digestive alpha-amylase in insect pests. This inhibition can cause digestive problems in insects in addition to their death.

From these above findings it was revealed that among the different treatments, T_6 showed the best result in reducing the number of cabbage semi-looper larvae (65.09%) than the other treatments; whereas, T_1 showed the least performance in reducing the number of cabbage semi-looper larvae (34.84%) over control. As a result, the order of rank of efficacy of the treatments applied against cabbage semi-looper including untreated control in terms of reducing number was $T_6 > T_5 > T_4 > T_2 > T_3 > T_1 > T_7$.

The different treatments of the botanicals influenced the incidence of cabbage semi-looper on the cabbage crop. The incidence was higher in the untreated plots during the experimental period compared to the plots treated with different botanicals. The neem-based insecticides are known to be an important source of triterpenoids (Siddiqui *et al*., 2004). The neem plants (*Azadirachta indica)* also contain salannin which discourages the insects to feed on them making the plants unpalatable (Gisbert *et al*., 2006). Triterpenoids and salannin in the neem-based insecticides might have acted as an antifeedant and also repelled the insects from feeding on the leaves of cabbage (Mondedji and Nyamador, 2019). The growth of various insect species is known to inhibited by neem seed extracts (Shannag *et al*., 2014).

Table 5. Effect of treatments on incidence of cabbage semi-looper per five plants.

Treatments	Number of cabbage semi-looper per five plants					Mean	% reduction over control
	20 DAT	30 DAT	40 DAT	50 DAT	60 DAT		
T_1	12.00 b	13.00 b	10.67 b	9.67 b	5.73 b	10.21 b	34.84
T_2	10.33 cd	11.33 cd	9.33 c	8.33 cd	5.27 b	8.92 c	43.08
T_3	11.33 bc	12.33 bc	10.33 b	9.33 bc	5.70 b	9.81 b	37.39
T_4	9.33 de	10.33 de	8.33 d	7.33 de	5.10 b	8.09 d	48.37
T_5	8.67 e	9.67 e	7.67 d	6.33 e	4.33 c	7.33 e	53.22
T_6	6.33 f	7.33 f	5.33 e	4.83 f	3.50 d	5.47 f	65.09
T_7	13.67 a	15.00 a	15.33 a	17.00 a	17.33 a	15.67 a	-
LSD $_{(0.05)}$	1.12	1.19	0.84	1.16	0.69	0.71	-
CV%	6.15	5.91	4.93	7.29	5.84	4.24	-

[DAT= Days after transplanting, in a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

4.2.2 Incidence of tobacco caterpillar

Significant variations ($p>0.05$) were observed among different treatments used for the management practices in terms of number of tobacco caterpillar larvae (Plate 4) at different days after transplanting (DAT). At 20 DAT, the highest number of tobacco caterpillar larvae per five plants was recorded in T_7 (16.00 larvae/5 plants) which was statistically different from all other treatments followed by T_1 (15.00 larvae/5 plants) and T_3 (14.67 larvae/5 plants). On the other hand, the lowest number of tobacco caterpillar larvae per five plants was recorded in T_6 (11.00 larvae/5 plants) which was statistically different from all other treatments followed by T_4 (12.00 larvae/5 plants), T_5 (13.00 larvae/5 plants) and T_2 (13.33 larvae/5 plants) (Table 6).

At 30 DAT, the highest number of tobacco caterpillar larvae per five plants was recorded in T_7 (17.67 larvae/5 plants) which was statistically different from all other treatments followed by T_1 (14.67 larvae/5 plants) and T_3 (14.33 larvae/5 plants). On the other hand, the lowest number of tobacco caterpillar larvae per five plants was recorded in T_6 (10.67 larvae/5 plants) which was statistically similar to that of T_4 (11.67 larvae/5 plants) but different from all other treatments and followed by T_5 (12.67 larvae/5 plants) and T_2 (13.33 larvae /5 plants). More or less similar trends of number of tobacco caterpillar per five plants were also recorded at 40 DAT, 50 DAT and 60 DAT.

In case of mean number of tobacco caterpillar larvae, the highest number of tobacco caterpillar larvae was recorded in T_7 (18.33 larvae/5 plants) which was significantly different from all other treatments followed by T_1(13.13 larvae/5 plants) and T_3 (12.33 larvae /5 plants). On the other hand, the lowest number of tobacco caterpillar larvae was recorded in T_6 (9.17 larvae/5 plants) which was statistically different from all other treatments followed by T_4 (10.13 larvae/5 plants), T_5 (11.13 larvae/5 plants) and T_2 (11.53 larvae/5 plants) (Table 6).

Considering the percent reduction of number of tobacco caterpillar larvae among different management practices over control, the highest reduction over control was achieved in T_6 (49.97%) followed by T_4 (44.74%) and T_5 (39.27%). On the other hand, the minimum reduction of number of tobacco caterpillar larvae over control was found in T_1 (28.34%) followed by T_3 (32.74%) (Table 6). More or less similar result was obtained by Reddy *et al.* (2017). They found 45.04% and 68.00% population reduction of tobacco caterpillar (*Spodoptera litura* Fab.) by applying azadirachtin (0.03%) at 7 DAS (Days After Spraying) and 10 DAS, respectively.

From these above findings it was revealed that among the different treatments, T_6 showed the best result in reducing the number of tobacco caterpillar larvae (49.97%) than the other treatments; whereas, T_1 showed the least performance in reducing the number of tobacco caterpillar larvae (28.34%) over control. As a result, the order of rank of efficacy of the treatments applied against tobacco caterpillar including untreated control in terms of reducing number was $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

Neem based insecticides are known to act as a deterrent causing the insects to stop feeding. It is due the disruption of the normal development of the insects interfering with the synthesis of chitin which is one of the growths regulating properties of neem-based insecticides. Neem oils are known to be effective in a number of different ways. A coating is formed on the insect's body by these neem oils which blocks the respiratory openings and the insects suffer from suffocation that ultimately leads to the death of the insects. Repellent properties of the neem oils are also revealed by some studies that are effective on certain species of insects and mites (Joshy *et al*., 2020).

Table 6. Effect of management practices on incidence of tobacco caterpillar per five plants.

Treatments	Number of tobacco caterpillar per five plants					Mean	% reduction over control
	20 DAT	30 DAT	40 DAT	50 DAT	60 DAT		
T_1	15.00 b	14.67 b	14.33 b	12.33 b	9.33 b	13.13 b	28.34
T_2	13.33 c	13.33 cd	12.67 c	10.67 c	7.67 c	11.53 c	37.09
T_3	14.67 b	14.33 bc	14.00 b	12.00 b	9.17 b	12.33 b	32.74
T_4	12.00 d	11.67 ef	11.33de	9.33 de	6.33 d	10.13 d	44.74
T_5	13.00 c	12.67 de	12.33 d	10.33 cd	7.33 c	11.13 c	39.27
T_6	11.00 e	10.67 f	10.33 e	8.33 e	5.50 d	9.17 e	49.97
T_7	16.00 a	17.67 a	19.00 a	20.00 a	19.00 a	18.33 a	-
LSD $_{(0.05)}$	0.98	1.01	1.31	1.31	0.91	0.89	-
CV%	4.05	4.15	5.47	6.2	5.59	4.05	-

[DAT= Days after transplanting, in a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

4.2.3 Incidence of diamondback moth larvae

Significant variations ($p>0.05$) were observed among different treatments used for the management practices in terms of number of diamondback moth larvae (Plate 4) at different days after transplanting (DAT). At 20 DAT, the highest number of diamond back moth larvae per five plants was recorded in T_7 (8.67 larvae/5 plants) which was statistically different from all other treatments followed by T_1 (7.33 larvae/5 plants) and T_3 (6.33 larvae/5 plants). On the other hand, the lowest number of diamond back moth larvae per five plants was recorded in T_6 (3.77 larvae/5 plants) which was statistically different from all other treatments followed by T_5 (4.60 larvae/5 plants), T_4 (5.53 larvae/5 plants) and T_2 (5.90 larvae/5 plants) (Table 7).

At 30 DAT, the highest number of diamond back moth larvae per five plants was recorded in T_7 (8.33 larvae/5 plants) which was statistically different from all other treatments followed by T_1 (6.33 larvae/5 plants) and T_3 (5.50 larvae/5 plants). On the other hand, the lowest number of diamond back moth larvae per five plants was recorded in T_6 (3.50 larvae/5 plants) which was statistically different from all other treatments and followed by T_5 (4.30 larvae/5 plants). More or less similar trends of number of tobacco caterpillar per five plants were also recorded at 40 DAT, 50 DAT and 60 DAT.

In case of mean number of diamond back moth larvae, the highest number of diamond back moth larvae was recorded in T_7 (9.87 larvae/5 plants) which was significantly different from all other treatments followed by T_1(5.92 larvae/5 plants) and T_3 (5.41 larvae /5 plants). On the other hand, the lowest number of diamond back moth larvae was recorded in T_6 (3.30 larvae/5 plants) which was statistically different from all other treatments followed by T_5 (4.04 larvae/5 plants), T_4 (4.83 larvae/5 plants) and T_2 (5.28 larvae/5 plants) (Table 7).

Considering the percent reduction of number of diamond back moth larvae among different management practices over control, the highest reduction over control was achieved in T_6 (66.57%) followed by T_5 (59.07%) and T_4 (51.06%). On the other hand, the minimum reduction of number of diamond back moth larvae over control was found in T_1 (40.02%) followed by T_3 (45.12%) which was very close to T_2 (46.50%) (Table 7). This result agreed with Dey *at el.* (2017). They reported that (70-74) % larval mortality of diamondback moth can be obtained by applying neem-based insecticides.

From these above findings it is revealed that among the different treatments, T_6 showed the best result in reducing the number of diamond back moth larvae (66.57%) than the other treatments; whereas, T_1 showed the least performance in reducing the number of diamond back moth larvae (40.02%) over control. As a result, the order of rank of efficacy of the treatments applied against diamond back moth including untreated control in terms of reducing number was $T_6 > T_5 > T_4 > T_2 > T_3 > T_1 > T_7$.

Botanicals possess properties like repellency, ant-feeding, quick knockdown, and flushing action. Indeed, the consumption of neem extract-treated leaves affected the development of the 4th stage larva of diamondback moth and reduced the larval population by causing death (Mochiah *et al.*, 2011). As a result, the emergence of the adult is reduced. This is due to the synergistic effect of the chemical compounds of the neem-based insecticides regulating the growth of the insects. Irregular development of the larval stage resulted in the abnormal wing shape. This is due to the disruption of the hormonal control of metamorphosis and moulting (Mondedji *et al*., 2020). Wing deformation could also be due to the extensive cellular injuries that causes cytotoxic effects and alter the organism's physiology. To control this species wing deformation is an advantage as it prevents the adult to fly that reduces it's movement and ultimately the plant infestation (Scudeler *et al*., 2014).

Table 7. Effect of treatments on incidence of diamondback moth larvae per five plants of cabbage.

Treatments	Number of diamondback moth larvae per five plants					Mean	% reduction over control
	20 DAT	30 DAT	40 DAT	50 DAT	60 DAT		
T_1	7.33 b	6.33 b	5.50 b	5.30 b	5.12 b	5.92 b	40.02
T_2	5.90 cd	5.43 c	5.23 b	5.03 b	4.78 b	5.28 c	46.50
T_3	6.33 c	5.50 c	5.27 b	5.07 b	4.88 b	5.41 bc	45.12
T_4	5.53 d	5.27 c	4.92 b	4.67 bc	3.78 c	4.83 c	51.06
T_5	4.60 e	4.30 d	4.10 c	3.87 cd	3.35 cd	4.04 d	59.07
T_6	3.77 f	3.50 e	3.28 d	3.08 d	2.87 d	3.30 e	66.57
T_7	8.67 a	8.33 a	9.67 a	11.00 a	11.67 a	9.87 a	-
LSD $_{(0.05)}$	0.63	0.75	0.69	0.94	0.63	0.61	-
CV%	5.89	7.61	7.19	9.75	6.78	6.26	-

[DAT= Days after transplanting, in a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

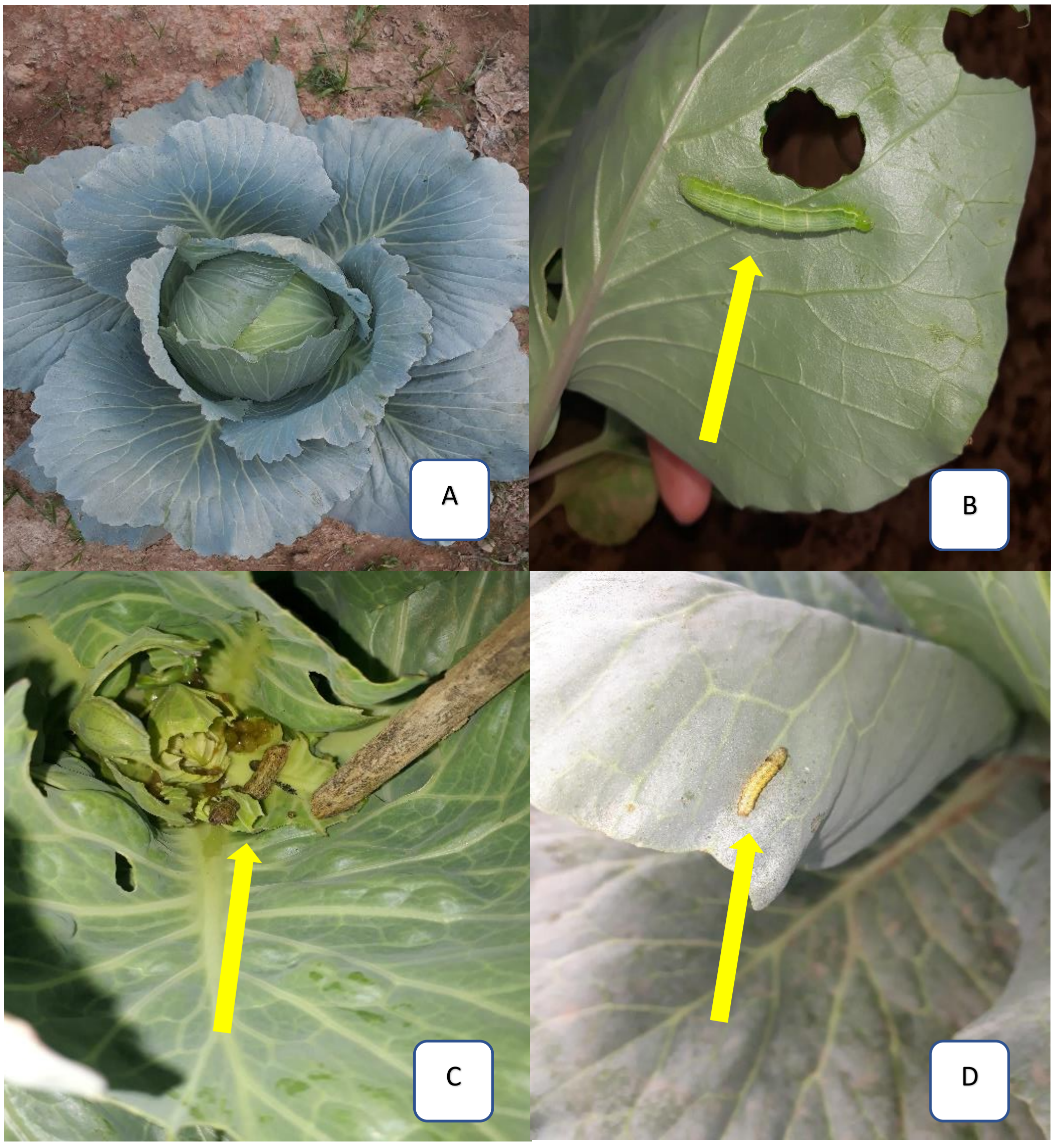


Plate 4. (A) Healthy cabbage head, (B) Cabbage semi-looper, (C) Tobacco caterpillar (*Spodoptera litura*), (D) Diamondback moth larvae

4.3 Effect of treatments on cabbage head infestation

The highest number of healthy cabbage head was recorded in T_6 (8.50), which was statistically similar to that of T_4 (8.33) and T_5 (7.92). On the other hand, the lowest number of healthy cabbage head was recorded in T_7 (6.67) which was statistically different from all other treatments and followed by T_1 (7.38) (Table 8). The highest number of cabbage head infestation was recorded in T_7 (4.22) which was statistically different from all other treatments and followed by T_1 (2.45). But the lowest number of cabbage head infestation was recorded in T_6 (1.30) which was statistically different from all other treatments and followed by T_4 (1.63) and T_5 (1.73). Considering the percent cabbage head infestation, the highest 42.23% infestation was recorded in T_7 which was statistically different from all other treatments and followed by T_1 (24.50). On the other hand, the minimum cabbage head infestation by number was recorded in T_6 (13.00%) which was statistically different from all other treatments and followed by T_4 (16.33%) and T_5 (17.33%).

From these above findings it is revealed that among different treatments, the Neem oil (T_6) reduced the highest infestation of cabbage head over control (69.22%) in the cabbage field. The lowest infestation reduction over control was found in T_1 (41.98%).

Table 8. Effect of management practices on cabbage head infestation.

Treatments	Healthy head	Infested head	Infestation (%)	Infestation reduce over control (%)
T_1	7.38 b	2.45 b	24.50 b	41.98
T_2	7.53 b	2.13 c	21.33 c	49.49
T_3	7.43 b	2.20 c	22.00 c	47.90
T_4	8.33 a	1.63 d	16.33 d	61.33
T_5	7.92 ab	1.73 d	17.33 d	58.96
T_6	8.50 a	1.30 e	13.00 e	69.22
T_7	6.67 c	4.22 a	42.23 a	--
LSD (0.05)	0.7	0.14	1.36	--
CV (%)	5.14	3.41	3.41	--

[In a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

4.4 Effect of treatments on yield and yield contributing characters of cabbage

4.4.1 Diameter of cabbage head

Significant variations were observed among the different treatments used for the management practices in terms of diameter of head due to attack of different insect pests during harvesting period (Table 9). The highest diameter of head (21.58 cm) was recorded in T_6 treated plot which was statistically different from all other treatments followed by T_4 (20.41 cm) and T_5 (19.37 cm). On the other hand, the lowest head diameter (14.87) was recorded in T_7 which was significantly different from all other treatments. But among the treated plots, the lowest head diameter (16.36 cm) was found in T_1 treated plot which was followed by T_3 (17.97 cm) and T_2 (18.23 cm). The gradually decreased trend was observed in case of diameter of head as recorded in $T_6 > T_4 > T_5 > T_2 > T_3 > T_{1,}$ treated plot > untreated control plot (T_7).

In terms of % increase over control, the highest increase over control on head diameter was observed in treatment of T_6 (45.12%) plot where the lowest was achieved from T_1 (10.02%).

From the above-mentioned findings, it is revealed that among the different treatments, T_6 performed the best in percent increasing diameter of head over control (45.12%) at harvest than the other treatments; whereas, T_1 showed the least performance in percent increasing diameter of head (10.02%) at harvest over control. As a result, the order of rank of efficacy among the different treatments including untreated control in terms of percent increasing diameter of head at harvest was $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_{7.}$

4.4.2 Height of cabbage head

Significant variations were observed among the different treatments used for the management practices in terms of height of head due to attack of different insect pests during harvesting period (Table 9). The highest height of head (10.23 cm) was recorded in T_6 which was statistically similar to that of T_4 (9.79 cm).

On the other hand, the lowest height of head (7.10 cm) was found in T_7 plot which was significantly different from all other treatments. But among the treated plots, the lowest height of head (8.17 cm) was recorded in T_1 which was followed by T_3 (8.20 cm), T_2 (8.92 cm) and T_5 (9.25 cm). The gradually decreased trend was observed in case of height of head as $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

In terms of % increase over control, the highest increase over control on head height was observed in the treatment of T_6 (44.05%) followed by T_4 (37.89%) whereas the lowest was achieved from T_1 (15.07%) which was very close to T_3 (15.49%) (Table 9).

From the above-mentioned findings, it was revealed that among the different treatments, T_6 performed the best in percent increasing height of head (44.05%) over control at harvest than the other treatments; whereas, T_1 showed the least performance in percent increasing height of head (15.07%) at harvest over control. As a result, the order of trend of efficacy among the different treatments including untreated control in terms of in percent increasing height of head at harvest was recorded in $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

Table 9. Effect of different treatments on yield contributing characters of cabbage.

Treatment	Diameter of head (cm)	% increase over control	Height of head (cm)	% increase over control
T_1	16.36 d	10.02	8.17 d	15.07
T_2	18.23 c	22.59	8.92 c	25.64
T_3	17.97 c	20.85	8.20 d	15.49
T_4	20.41 b	37.26	9.79 ab	37.89
T_5	19.37 b	30.26	9.25 bc	30.28
T_6	21.58 a	45.12	10.23 a	44.05
T_7	14.87 e	--	7.10 e	--
LSD (0.05)	1.08	--	0.66	--
CV (%)	3.31	--	4.23	--

[In a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

4.4.3 Single head weight (kg) during harvest

Significant variations were observed among the different treatments used for the management practices in terms of single head weight at the time of harvest (Table 10). The highest single head weight (1.46 kg) was recorded in T_6 which was statistically different from all other treatments and followed by T_4 (1.27 kg) and T_5 (1.23 kg).

On the other hand, the lowest single head weight (0.94 kg) was found in T_7 which was significantly different from all other treatments. But in the treated plots, the lowest single head weight (1.03 kg) was found in T_1 which was followed by T_3 (1.12 kg) and T_2 (1.19 kg). The gradually decreased rank was observed in case of single head weight as recorded in $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$. (Table 10).

In terms of % increase over control, the highest increase over control on single head weight was observed in T_6 (55.32%) treated plot whereas the lowest was recorded from T_1 (9.57%) (Table 10). As a result, the order of rank of efficacy among the different treatments including untreated control in terms of in percent increasing diameter of head at harvest was found in $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

4.4.4 Total yield (t/ha)

Significant variations were observed among the different treatments used for the management practices in terms of total yield (t ha^{-1}) due to attack of different insect pests at harvest (Table 10). The highest total yield (36.50 t ha^{-1}) was recorded in T_6 treated plot which was statistically different from all other treatments followed by T_4 (31.83 t ha^{-1}) and T_5 (30.67 t ha^{-1}). The lowest total yield (23.08 t ha^{-1}) was found in T_7 which was significantly different from all other treatments. But in the treated plots, the lowest total yield (25.75 t ha^{-1}) was found in T_1 which was followed by T_3 (28.08 t ha^{-1}) and T_2 (29.75 t ha^{-1}This result was supported by Dey *et al.* (2017) where they obtained an average yield of 27.58-39.1 t ha^{-1} by applying different botanical insecticides. The gradually decreased trend was observed in case of total yield as in $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

In terms of % increase over control, the highest increase over control on total yield (t/ha) was observed in treatment of T_6 (58.15%) which followed by T_4 (37.91%) and T_5 (32.89%) whereas the lowest was achieved from T_1 (11.57%) followed by T_3 (21.66%) (Table 8). As a result, the order of rank of efficacy among the different treatments including untreated control in terms of percent increase of total yield (t ha^{-1}) at harvesting was $T_6 > T_4 > T_5 > T_2 > T_3 > T_1 > T_7$.

Table 10. Individual head weight and total yield (ton/ha) of cabbage in different treatments during harvesting.

Treatment	Single head wt. (kg)	% increase over control	Total yield(ton/ha)	% increase over control
T_1	1.03 e	9.57	25.75 e	11.57
T_2	1.19 c	26.59	29.75 c	28.89
T_3	1.12 d	19.15	28.08 d	21.66
T_4	1.27 b	35.11	31.83 b	37.91
T_5	1.23 bc	30.85	30.67 bc	32.89
T_6	1.46 a	55.32	36.50 a	58.15
T_7	0.94 f	--	23.08 f	--
LSD (0.05)	0.06	--	1.63	--
CV (%)	2.52	--	3.12	--

[In a column, numeric value represents the mean of 3 replications; each replication is derived from 5 plants per treatment; in a column means having similar letter(s) are statistically identical at 0.05 level of probability]

[T_1: Spraying of Mahogany seed kernel extract @ 3 ml/L of water at 7 days interval;T_2: Spraying of Tobacco leaf extract @ 3 ml/L of water at 7 days interval; T_3: Spraying of Garlic extract @ 3 ml/L of water at 7 days interval; T_4: Spraying of Neem leaf extract @ 3 ml/L of water at 7 days interval; T_5: Spraying of Neem seed kernel extract @ 3 ml/L of water at 7 days interval; T_6: Spraying of Neem oil @ 3 ml/L of water at 7 days interval; T_7: Untreated control]

4.5 Relationship between leaf infestation by semi-looper and yield of cabbage

The results revealed that there was strong negative correlation between leaf infestation by semi-looper and total yield/ha, which suggested that with the increase of leaf infestation intensity there was a decrease on total yield/ha. A linear regression was fitted between total yield/ha and leaf infestation by semi-looper (Figure 3). The correlation coefficient (r) was – 0.948 and the contribution of the regression (R^2) was 0.9. In the present study, it was observed that semi-looper infestation on leaf passively prevented plants to produce and supply nutrient and water. The plants became stunted and produced a reduced yield.

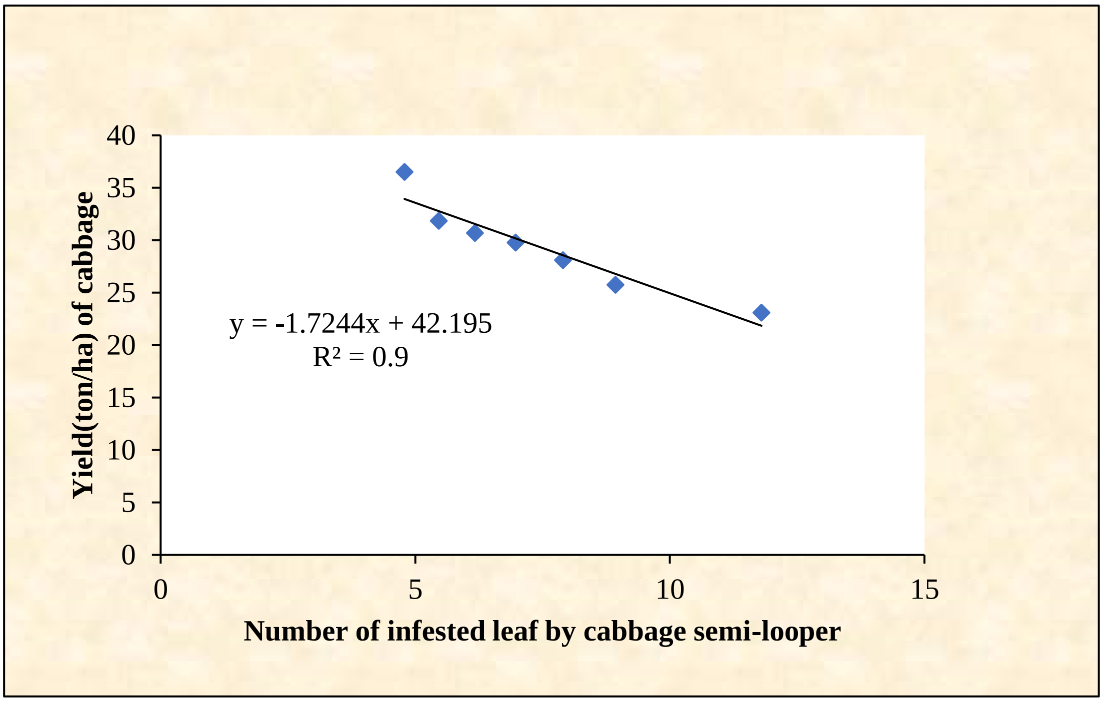


Figure 3. Relationship between leaf infestation by semi-looper and yield of cabbage.

4.6 Relationship between leaf infestation by tobacco caterpillar and yield of cabbage

Significant relationship was found between leaf infestation by tobacco caterpillar and yield of cabbage when correlation was made between these two parameters. There was a very strong (R^2=0.892) and negative (slope =-1.291) correlation found between leaf infestation by tobacco caterpillar and yield of cabbage, i.e., yield of cabbage decreased with the increasing of cabbage leaf infestation by caterpillar. Tobacco caterpillar infestation on leaf passively prevented plants to produce and supply nutrient and water. The plants became stunted with a reduced yield.

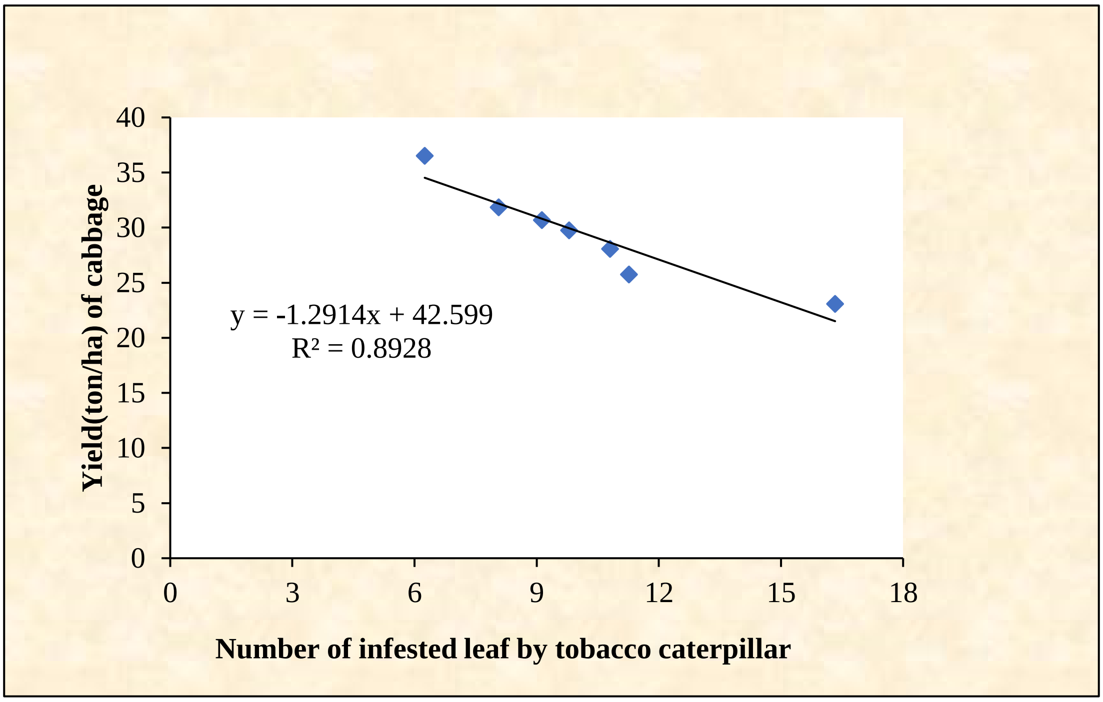


Figure 4. Relationship between leaf infestation by tobacco caterpillar and yield of cabbage.

4.7 Relationship between leaf infestation by diamondback moth larvae and yield of cabbage

Significant relationship was found when correlation was made between leaf infestation by diamondback moth larvae and yield of cabbage. The highly significant ($p<0.05$), very strong (R^2=0.8536) and negative (slope =-1.262) correlation was found between these two parameters, i.e., yield of cabbage decreased with the increase of leaf infestation by diamondback moth larvae. From the present study, it was revealed that leaf infestation by diamond back moth larvae passively prevented plants to produce and supply nutrient and water. The plants became stunted with a reduced yield.

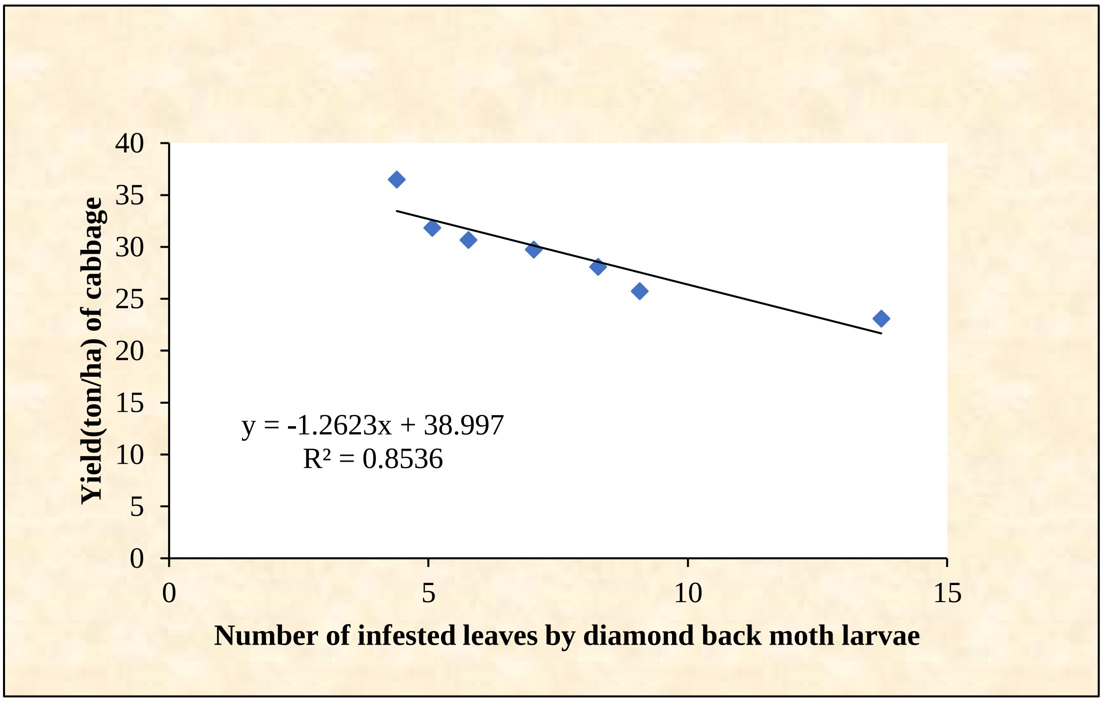


Figure 5. Relationship between leaf infestation by diamondback moth larvae and yield of cabbage.

4.8 Relationship between incidence of cabbage semi-looper and yield of cabbage

When correlation was made between incidence of cabbage semi-looper and yield of cabbage, significant relationship was found between these two parameters. The highly significant ($p<0.05$), very strong (R^2=0.848) and negative (slope =-1.246) correlation was found between incidence of cabbage semi-looper and yield of cabbage, i.e., yield of cabbage decreased with the increasing incidence of cabbage semi-looper. From these above findings, it was revealed that higher number of cabbage semi-looper larvae increases the leaf infestation of cabbage which passively prevented plants to produce and supply nutrient and water. The plants became stunted and resulted reduced yield.

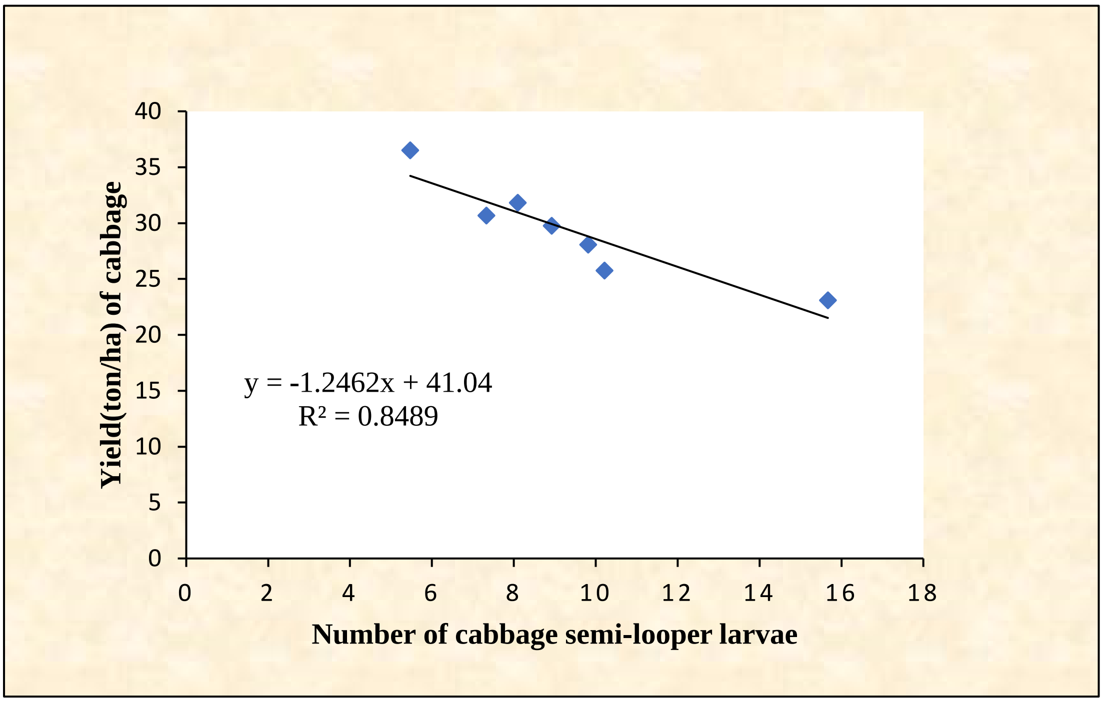


Figure 6. Relationship between incidence of semi looper and yield of cabbage.

4.9 Relationship between incidence of tobacco caterpillar and yield of cabbage

A highly significant ($p<0.05$), very strong ($R^2=0.8203$) and negative (slope =-1.3166) correlation was found between incidence of tobacco caterpillar and yield of cabbage when a linear regression was fitted between these two parameters, i.e., yield of cabbage decreased with the increasing incidence of tobacco caterpillar. From the present study, it is revealed that higher number of tobacco caterpillar larvae increased the leaf infestation of cabbage which passively prevented plants to produce and supply nutrient and water. As a result, plants became stunted with a reduced yield.

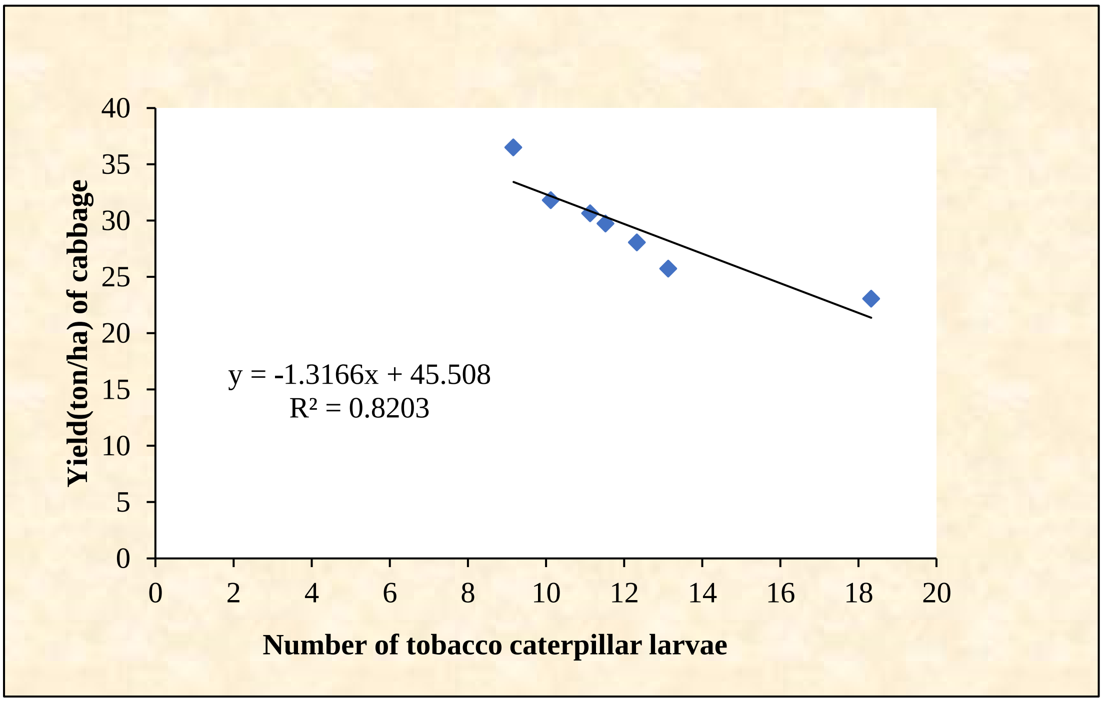


Figure 7. Relationship between incidence of tobacco caterpillar and yield of cabbage.

4.10 Relationship between incidence of diamondback moth larvae and yield of cabbage

A linear regression was fitted between the incidence of diamondback moth and yield of cabbage (t ha^{-1}) and a highly significant ($p<0.05$), very strong (R^2=0.7686) and negative (slope =-1.802) correlation was found between these two parameters, i.e., yield of cabbage decreased with the increasing number diamondback moth larvae. In the present study, it was revealed that the higher number of diamondback moth larvae led to the higher leaf infestation of cabbage which ultimately prevented plants to produce and supply nutrient and water. As a result, plants became stunted with a reduced yield.

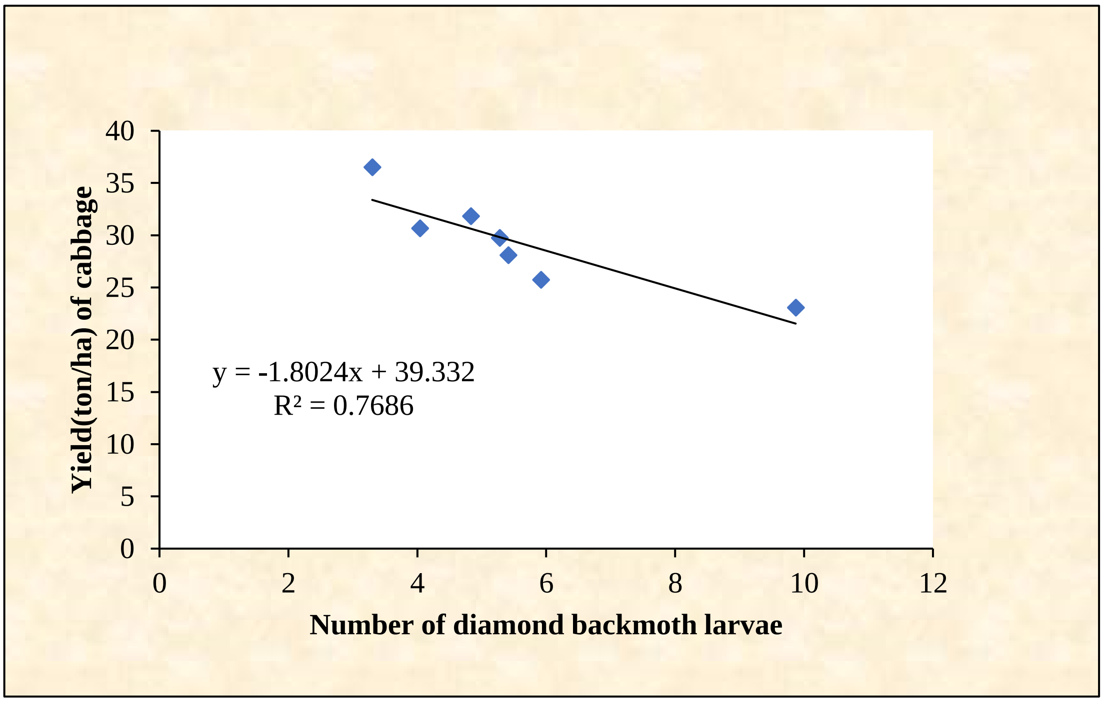


Figure 8. Relationship between incidence of diamondback moth larvae and yield of cabbage.

4.11 Relationship between diameter of cabbage head and yield of cabbage

Significant relationship was found between diameter of cabbage head and yield of cabbage when correlation was made between these two parameters. The highly significant ($p<0.05$), very strong ($R^2=0.9629$) and positive (slope =1.846) correlation was found between diameter of cabbage head and yield of cabbage, i.e., yield of cabbage increased with the increase of diameter of cabbage head.

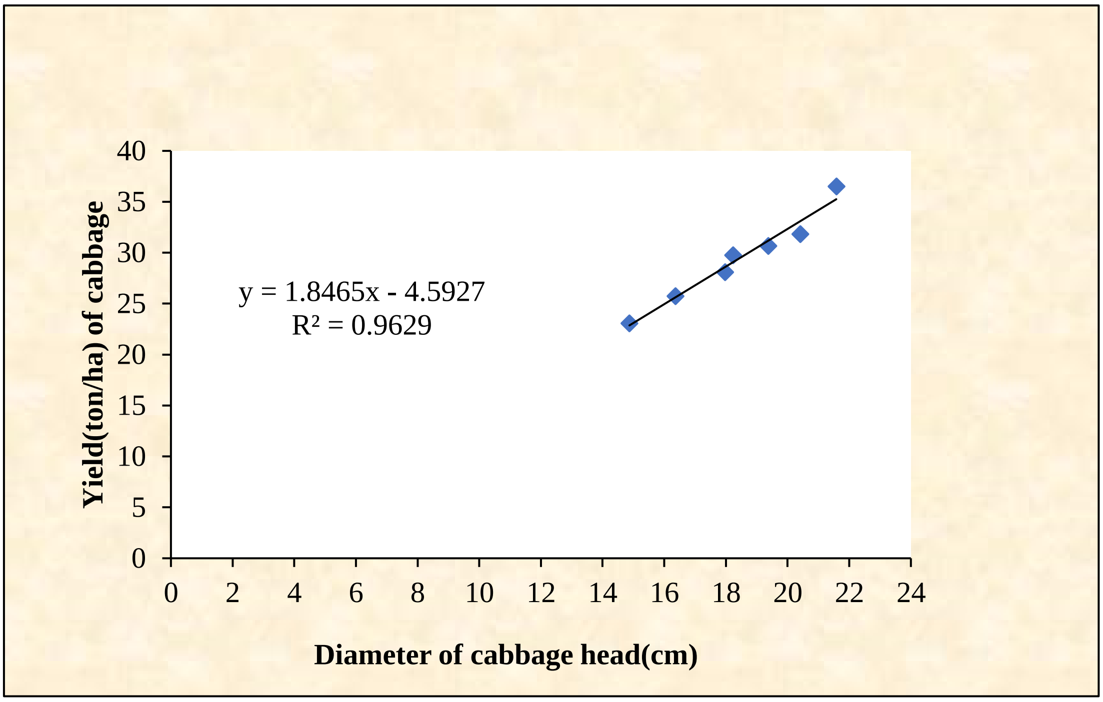


Figure 9. Relationship between diameter of cabbage head and yield of cabbage.

4.12 Relationship between height of cabbage head and yield of cabbage

When correlation was made between height of cabbage head and yield of cabbage, significant relationship was found between these two parameters. The highly significant ($p<0.05$), very strong (R^2=0.936) and positive (slope =3.921) correlation was found between height of cabbage head and yield of cabbage, i.e., yield of cabbage increased with the increasing height of cabbage head.

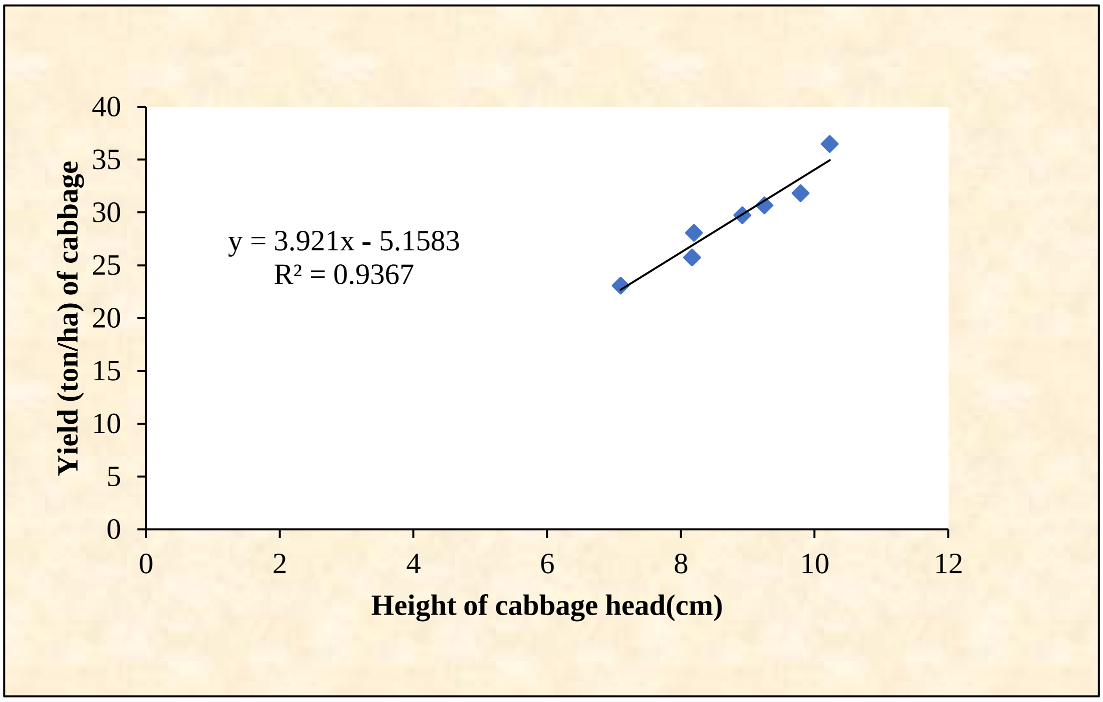


Figure 10. Relationship between height of cabbage head and yield of cabbage.

4.13 Relationship between percent head infestation during harvest and weight of individual head

The results revealed that there was strong negative correlation between head infestation intensity and weight of individual head (kg), which suggested that with the increase of head infestation intensity there was a decrease on single head weight (kg). A linear regression was fitted between weight of individual head and head infestation intensity at harvest (Figure 11). The correlation coefficient (r) was –0.871 and the contribution of the regression (R^2) were 0.759. In the present study, it was observed that infestation on head passively prevented plants to produce and supply nutrient and water. The plants became stunted with a reduced single head weight.

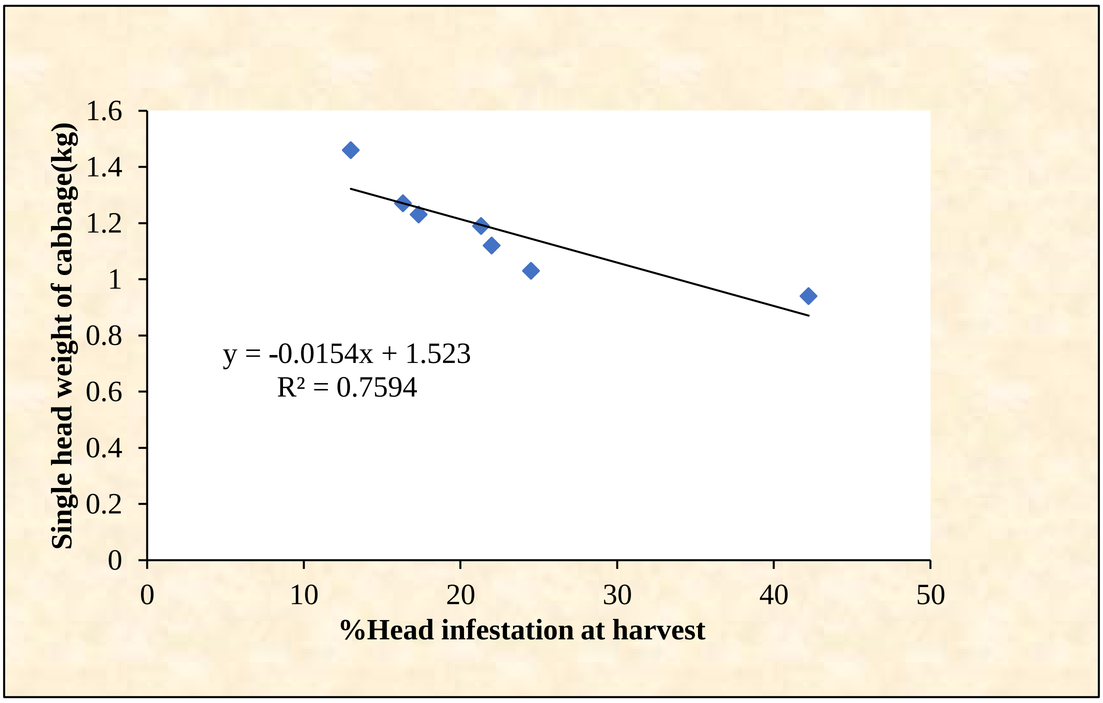


Figure 11. Relationship between percent head infestation during harvest and weight of individual head among different treatments.

4.14 Relationship between percent head infestation during harvest and total yield of cabbage (t ha^{-1}) among different treatments.

A linear regression was fitted between total yield of cabbage (t ha^{-1}) and percent head infestation at harvest (Figure 12). The results revealed that there was strong negative correlation between head infestation intensity and total yield (t ha^{-1}), which suggested that with the increase of head infestation intensity there was a significant decrease on total yield of cabbage. The correlation coefficient (r) was – 0.885 and the contribution of the regression (R^2) were 0.784. In the present study, it was observed that infestation on head passively prevented plants to produce and supply nutrient and water. The plants became stunted with a reduced yield.

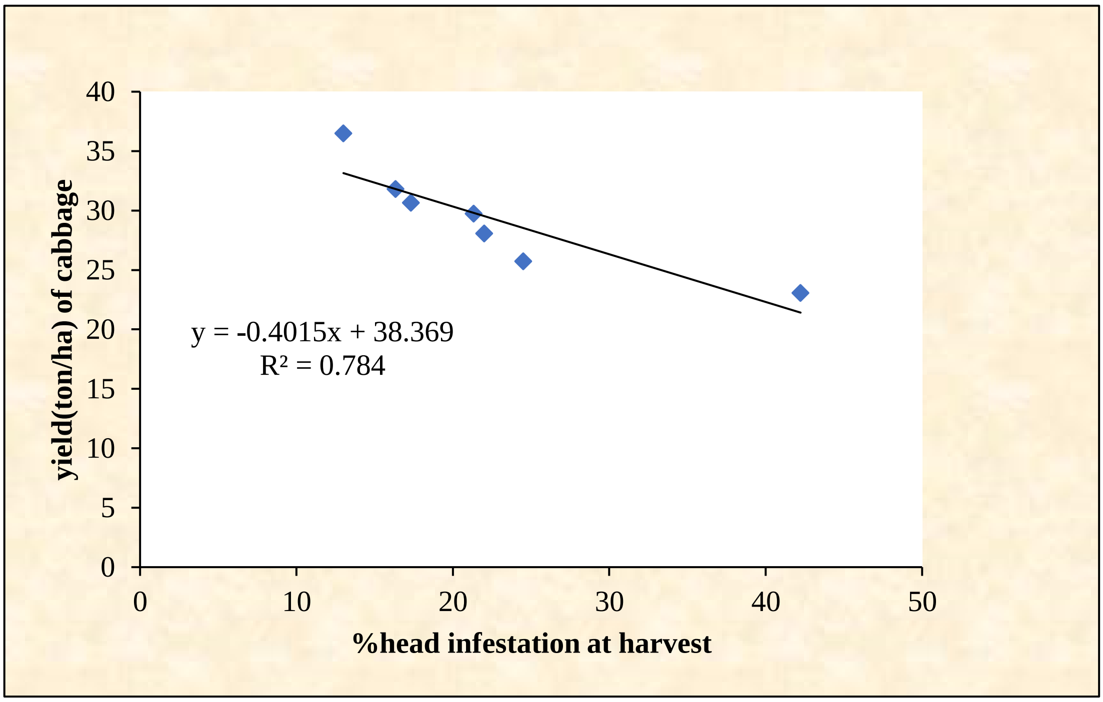


Figure 12. Relationship between percent head infestation during harvest and total yield of cabbage (t ha^{-1}) among different treatments.

SUMMARY AND CONCLUSION

The study was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from May, 2018 to September, 2018 to evaluate some management practices applied against major Lepidopteran insect pests of summer cabbage. The experiment consisted of control measures with some botanicals.

Six treatments, viz., T_1 (Mahogany seed kernel extract @ 3.0 ml/L of water at 7 days interval); T_2 (Tobacco leaf extract @ 3.0 ml/L of water at 7 days interval); T_3 (Garlic extract @ 3.0 ml/L of water at 7 days interval); T_4 (Neem leaf extract @ 3.0 ml/L of water at 7 days interval); T_5 (Neem seed kernel extract @ 3.0 ml/L of water at 7 days interval); T_6 (Neem oil @ 3.0 ml/L of water at 7 days interval) and an untreated control (T_7) were included in this study. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

Results showed that the significant variations were observed among different ages of the cabbage plant in terms of percent leaf infestation and percent head infestation. From the beginning of head formation stage to harvest, significant results were observed in terms of leaf infestation intensity, percent infestation of head by number, percent head infestation by weight, height of head, diameter of head, single head weight (kg), healthy head weight (kg) and total yield (t ha^{-1}).

Results showed that the lowest number of infested leaves by cabbage semi-looper (4.77, 5.50, 5.17, 4.67 and 3.87 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean of = 4.79 was observed in T_6 treated plot while the highest (10.67, 11.00, 11.67, 13.00 and 12.67 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 11.80) was obtained from untreated control plot (T_7). But among the treated plots, the highest leaf infestation by number (9.33, 10.33, 9.33, 8.33 and 7.33 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 8.93) was achieved from T_1 treated plot. In terms of percent reduction of leaf infestation among different treatments, the highest reduction over control was found in T_6 (59.40%) and the lowest was in T_1 (24.32%).

In case of tobacco caterpillar, the lowest number of infested leaves (7.33, 6.33, 6.67, 5.67 and 5.27 at 20, 30, 40, 50 and 60 DAT, respectively i.e. mean = 6.25) was observed in T_6 treated plot where the highest (14.33, 15.33, 16.00, 17.00 and 19.00 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 16.33) was obtained from untreated control plot (T_7). But among the treated plots, the highest leaf infestation by number (11.67, 11.33, 12.33, 11.00 and 10.00 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 11.27) was achieved from T_1 treated plot.

In terms of percent reduction of leaf infestation among different treatments, the highest reduction over control was found in T_6 (61.73%) and the lowest was found in T_1 (30.99%) treated plot.

Likewise, the lowest number of infested leaves by diamondback moth larvae (4.43, 4.83, 4.60, 4.30 and 3.80 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 4.39) was observed in T_6 treated plot where the highest (10.67, 13.00, 14.00, 15.33 and 15.67 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 13.73) was obtained from untreated control plot (T_7). But among the treated plots, the highest leaf infestation by number (9.67, 10.67, 9.33, 8.33 and 7.33 at 20, 30, 40, 50 and 60 DAT, respectively i.e., mean = 9.07) was achieved from T_1 treated plot. In terms of percent reduction of leaf infestation among different treatments, the highest reduction over control was found in T_6 (68.03%) and the lowest was found in T_1 (33.94%) treated plot.

In case of incidence of different insects, the lowest mean number of different insects larvae per five plants was found in T_6 (5.47,9.17 and 3.30 for cabbage semi-looper, tobacco caterpillar and diamondback moth, respectively). On the other hand, the highest mean number of cabbage semi-looper, tobacco caterpillar and diamondback moth larvae per five plants was found in T_7 (15.67,18.33 and 19.87 respectively).In terms of percent reduction over control among different treatments,T_6 showed the highest incidence reduction over control (65.09%,49.97% and 66.57% against cabbage semi-looper, tobacco caterpillar and diamondback moth, respectively. The lowest reduction over control was found in T_1 (34.84%,28.34% and 40.02% against cabbage semi-looper, tobacco caterpillar and diamondback moth, respectively.

Consequently, during harvesting period the lowest number infested head (1.30), percent infestation of head (13.00 %), highest height of head (10.23 cm), diameter of head (21.58 cm), single head weight (1.46 kg) and highest total yield (36.50 t/ha) were observed in T_6 treated plot where the highest number of infested head (4.22), percent infestation of head (42.23%), the lowest height of head (7.10 cm), diameter of head (14.87 cm), single head weight (0.94 kg) and the lowest total yield (23.08 t ha^{-1}) were obtained from T_7. But in the treated plots, the highest number of infested head (2.45), percent infestation of head (24.50%), the lowest height of head (8.17 cm), diameter of head (16.36 cm), single head weight (1.03 kg) and the lowest total yield (25.75 t ha^{-1}) were obtained from T_1 treated plot.

In terms of percent reduction or increase over control the highest percent reduction of head infestation over control (69.22%), percent increase of height of head over control (44.05%), percent increase of diameter of head over control (45.12%) and percent increase of Total yield over control (58.15%) were achieved from T_6 treated plot where the lowest percent reduction of head infestation over control (41.98%), percent increase of height of head over control (15.07%), percent increase of diameter of head over control (10.02 %) and percent increase of total yield over control (11.57%) were achieved from T_1 treated plot.

From the above findings, it can be concluded that, the treatment T_6 comprised of Neem oil @ 3.0 ml/L of water applied at 7 days interval gave the best performance compared to all other treatments used under the present study while the lowest performance was obtained from untreated control treatment. On the other hand, T_1 (Mahogany seed kernel extract @ 3.0 ml/L of water at 7 days interval) showed poorest result among the botanicals tested.

RECOMMENDATIONS

Considering the findings of the present experiment, further studies in the following areas may be suggested:

1. Diversity of insect pests may be studied for several years all over Bangladesh to identify the major insect pests of summer cabbage.

2. Further trials with effective botanicals may be done at different locations of the country.

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APPENDICES

Appendix I. Experimental site at Sher-e-Bangla Agricultural University, Dhaka-1207.

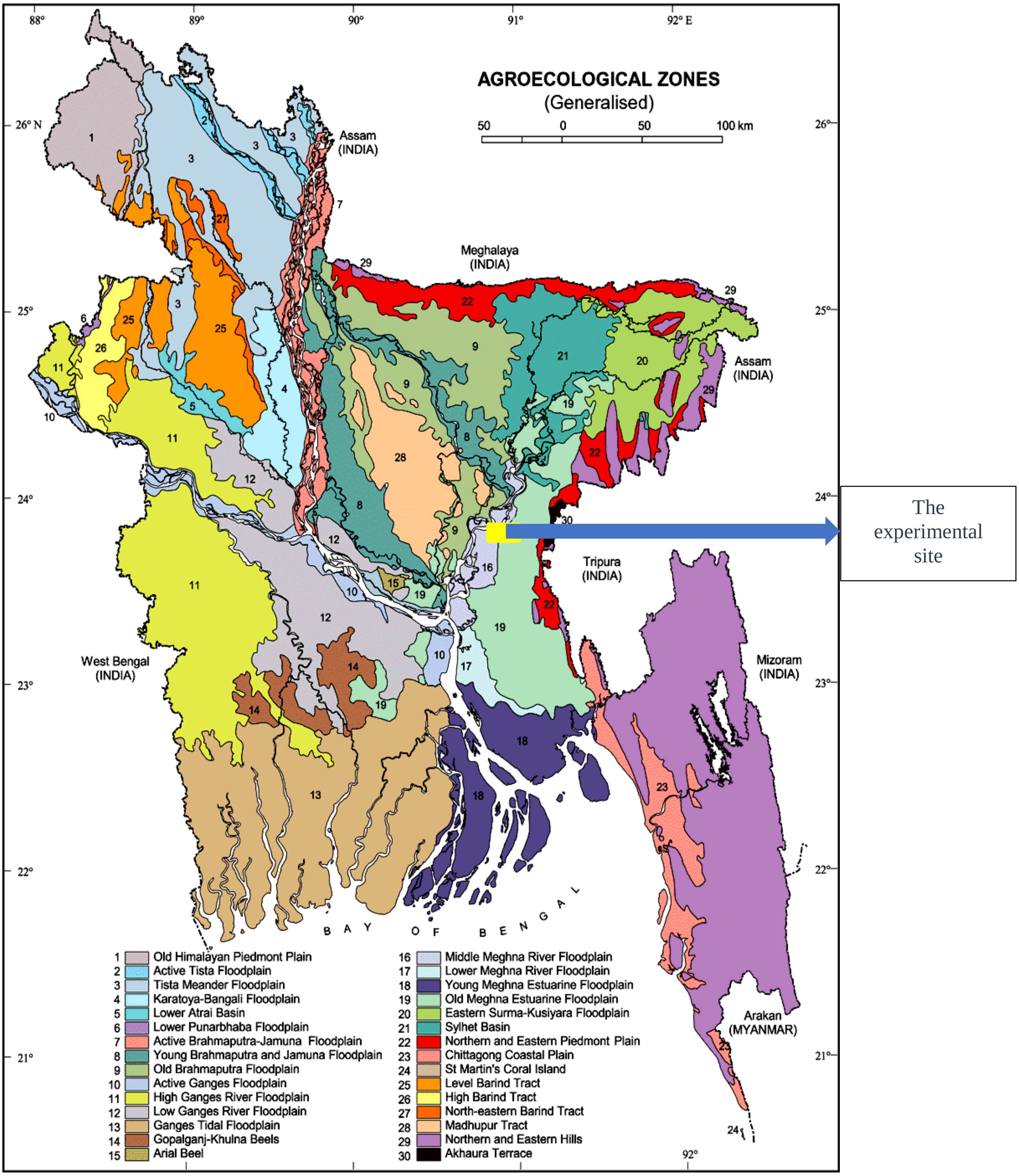

Figure: The map of Bangladesh showing experimental site.

Appendix II. Monthly average air temperature, relative humidity, rainfall and sunshine hours during the experimental period (May, 2018 to September, 2018) at Sher - e - Bangla Agricultural University campus.

Month	Air temperature (ºc)		Average Relative humidity (%)	Rainfall (mm) (total)	Average Daylength (hr)
	Maximum	Minimum			
May,2018	32.9	24.5	59	339.4	13.3
June, 2018	32.1	26.1	72	340.4	13.6
July, 2018	31.4	26.2	72	373.1	13.4
August, 2018	31.6	26.3	74	316.5	12.9
September, 2018	31.6	25.9	71	300.4	12.3

Source: Bangladesh Meteorological Department (Climate & Weather Division), Agargoan, Dhaka – 1212.

Appendix III. Physical characteristics and chemical composition of soil of the experimental plot.

Soil Characteristics	**Analytical results**
Agrological Zone	Madhupur Tract
PH	5.47 – 5.63
Organic matter	0.82
Total N (%)	0.43
Available phosphorous	22 ppm
Exchangeable K	0.42 meq / 100 g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka.

Appendix IV. Analysis of variance of the data on the leaf infestation of cabbage due to attack of Tobacco Caterpillar as influenced by different treatments.

Source of variance	Degrees of Freedom	Mean square of leaf infestation by number					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	Mean infestation
Replication	2	0.5714	0.333	1.476	1.857	0.166	0.499
Treatment	6	13.937**	23.539**	26.539**	38.444**	61.596**	30.266**
Error	12	0.294	0.444	0.421	0.302	0.555	0.169

** Significant at 0.01 level of probability;

Appendix V. Analysis of variance of the data on the leaf infestation of cabbage due to attack of cabbage semi-looper as influenced by different treatments.

Source of variance	Degrees of Freedom	Mean square of leaf infestation by number					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	Mean infestation
Replication	2	0.609	1.226	0.762	1.134	0.825	0.856
Treatment	6	13.485**	12.568**	15.679**	24.711**	25.809**	17.107**
Error	12	0.242	0.282	0.179	0.217	0.088	0.129

** Significant at 0.01 level of probability;

Appendix VI. Analysis of variance of the data on the leaf infestation of cabbage due to attack of diamondback moth larvae as influenced by different treatments.

Source of variance	Degrees of Freedom	Mean square of leaf infestation by number					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	Mean infestation
Replication	2	0.952	0.118	0.003	0.303	0.181	0.102
Treatment	6	15.063**	26.639**	31.062**	42.578**	50.139**	30.268**
Error	12	0.188	0.432	0.421	0.234	0.218	0.191

** Significant at 0.01 level of probability;

Appendix VII. Analysis of variance of the data on the incidence of tobacco caterpillar by number as influenced by different treatments.

Source of variance	Degrees of Freedom	Mean square of tobacco caterpillar by number					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	Mean incidence
Replication	2	3.857	0.429	0.429	0.428	1.583	0.201
Treatment	6	9.302**	15.746**	23.968**	44.539**	61.901**	26.919**
Error	12	0.302	0.318	0.539	0.539	0.264	0.249

** Significant at 0.01 level of probability;

Appendix VIII. Analysis of variance of the data on the incidence of cabbage semi-looper by number as influenced by different treatments.

Source of variance	Degrees of Freedom	Mean square of cabbage semi-looper by number					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	Mean incidence
Replication	2	0.619	1.0	1.002	0.218	0.043	0.461
Treatment	6	17.302**	18.492**	29.079**	46.123**	67.729**	30.891**
Error	12	0.397	0.444	0.222	0.489	0.153	0.157

** Significant at 0.01 level of probability;

Appendix IX. Analysis of variance of the data on the incidence of diamondback moth larvae by number as influenced by different treatments

Source of variance	Degrees of Freedom	Mean square of diamondback moth larvae by number					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	Mean incidence
Replication	2	0.632	0.123	0.134	0.029	0.310	0.181
Treatment	6	8.087**	7.109**	12.330**	19.932**	26.486**	13.351**
Error	12	0.126	0.177	0.152	0.281	0.125	0.119

** Significant at 0.01 level of probability;

Appendix X. Analysis of variance of the data on yield and yield contributing characters of Cabbage due to attack of different Lepidopterous insect pests at harvesting as influenced by different treatments

Source of variance	Degrees of Freedom	Mean square			
		Height of head	Diameter of head	Single head weight (kg)	Total yield (t/ha)
Replication	2	1.569	2.541	0.005	3.663
Treatment	6	3.455**	15.979**	0.087*	56.506**
Error	12	0.139	0.371	0.001	0.841

** Significant at 0.01 level of probability;
* Significant at 0.05 level of probability;