INCIDENCE OF INSECT PEST IN BROCCOLI AND THEIR ECOFRIENDLY MANAGEMENT USING NEEM PRODUCTS

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This is to certify that thesis entitled ***"INCIDENCE OF INSECT PEST IN BROCCOLI AND THEIR ECOFRIENDLY MANAGEMENT USING NEEM PRODUCTS"*** *submitted to the* ***Faculty of Agriculture,*** *Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS) IN ENTOMOLOGY*** *embodies the result of a piece of bona fide research work carried out by* ***NASRIN AKTER NIPA, Registration no. 13-05467*** *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.

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TO

MY BELOVED

PARENTS

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ABSTRACT

The present experiment was conducted to study the incidence of insect pests in broccoli and their eco-friendly management using neem products during November 2019 to February 2020 at the central experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. The experiment comprised of seven different treatments (neem oil, neem seed kernel extract, neem seed extract, neem leaf extract, neem bark, extract, neem bark powder and untreated control). The experiment was laid out in Randomized Complete Block Design with three replications. Different treatments expressed significant differences on morphological, physiological parameters, yield attributing traits and yield of broccoli. Among different treatments, neem oil showed the best performance in reducing the number of cabbage worm, diamondback moth, cabbage semi-looper, aphid and flea beetle (1.73 cabbage worm, 1.59 diamondback moth, 1.17 cabbage semi-looper, 1.16 aphid and 0.87 flea beetle, respectively), leaf infestation (15.41%) and plant infestation (33.33%) per five tagged plants and increased plant height, leaf length, leaf breadth, card length, card diameter, card perimeter and yield (42.69 cm, 40.12 cm, 13.76 cm, 22.11 cm, 20.11 cm, 38.23 cm, 16.23 ton ha^{-1}, respectively) of broccoli. The order of rank of efficacy of the treatments applied against the insect pests of broccoli was $T_1>T_4>T_2>T_3>T_6>T_5>T_7$. From the experiment it was revealed that, neam oil is a good botanicals against the insect pests of broccoli which is eco-friendly and non-hazardous to human health.

LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Full meaning
%	Percent
°C	Degree Celsius
AEZ	Agro-ecological Zone
AVOVA	Analysis of variance
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
cm	Centimeter
CV	Coefficient of variation
DAT	Days after transplanting
df.	Degrees of freedom
et al.	And others
FAO	Food and Agriculture Organization
G	Gram
Ha	Hectare
J.	Journal
Kg	Kilogram
LSD	Least Significant Difference
Mg	Milligram
Ml	Milliliter
MP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
TSP	Triple Super Phosphate

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CHAPTER I

INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica*) is the most important herbaceous biennial "Cole" crop under Brassicaceae family which is one of the leading vegetables in the world. The word broccoli comes from Italian word *broccolo*, which means 'flowering crest of a cabbage". Broccoli has large flower heads, usually green in color, arranged in a tree-like structure on branches sprouting from a thick, edible stalk. There are three classes of broccoli, i.e. green, white and purple, among them green type broccoli is the most popular (Shoemaker *et al.* 1962). Broccoli originated in West Europe. It is one of the uncommon winter vegetables in Bangladesh which is a horticultural hybrid closely related to cauliflower and is considered as a commercial crop in India (Nonnecke 1989). India is the second largest producer of broccoli after China, while the US ranks third. It is also used as a vegetable in many other countries such as Spain, Mexico, Italy, France, United States, etc. (Kumar *et al.* 2014). It is a minor vegetable in Bangladesh and commercial cultivation of broccoli has increased especially in the area of Dhaka and Gazipur districts. In Bangladesh it is planted in early September to late November (Ahmad and Shahjahan 1991). It is fairly rich in vitamin A, ascorbic acid and contains appreciable amounts of calcium, phosphorus, riboflavin, thiamin, niacin and iron (Nonnecke 1989). Watt (1983) reported that broccoli is more nutritious than any other cole crops such as cabbage, cauliflower and kohlrabi. Broccoli is environmentally better adapted than cauliflower and is reported to withstand comparatively at higher temperature than cauliflower (Rashid 1976). Broccoli can be grown on a wide range of soil types, ranging from light sand to heavy loam and even clay that are well supplied with organic matter (Katayal 1994). Successful production of broccoli depends on various factors. It requires 250-300 mm water during transplanting, growing period and curd formation stage (Rashid 1976). In most of the time irrigation increase the cost of production resulting in unprofitable production of broccoli and make growers frustrated.

In spite of being a prospective crop, high incidence of insect pests are one of the main factors for the reduction of its yield and quality. Farmers in our country faced various problems including the availability of quality seeds, fertilizer and manures, irrigation facilities, modern information in the fields, technical and instrumental inputs, pests and disease in cultivation of the crop (Rashid 1999). Among these problems, occurrence of frequent insect pest attack has been most important. Broccoli plants are attacked by more than 25 insect species (Bhoopathi and Pathak 2012). Major insects of broccoli are diamondback moth (*Plutella xylostella* L.), leaf webber (*Crocidolomia binotalis* Zeller), cabbage butterfly (*Pieris brassicae* L.), cabbage worm (*Pieris rapae* Sch.), mustard sawfly (*Athalia lugens proxima* Klug), aphid (*Brevicoryne brassicae* L.), painted bug (*Bagrada cruciferarum* Kirkaldy), cabbage webworm (*Hellula undalis* Feb.), termite (*Microtermes obesi* Holmgren), cutworm (*Agrotis ipsilon* Hufnagel), leaf eating weevil (*Tanymecus circumdatus* Wiedemann), cabage semilooper (*Trichoplusia ni* Hubner), leaf miner (*Chromatomyia horticola* Goureau), whitefly (*Bemisia tabaci* Gennadius), red spider mite (*Tetranychus urticae* Koch), crucifer flea beetle (*Phyllotreta cruciferae* Goeze), thrips (*Frankliniella occidentalis* Pergande) etc. There are some of the most common pests are cabbage worms, aphids, flea beetles, cutworms. Cabbage worms cause serious damage by feeding on broccoli leaves. Aphids are tiny, soft-bodied insects that feed on the undersides of broccoli leaves, causing them to become discolored and wrinkled. Flea beetles can kill seedlings and reduce the yield of mature plants. Cutworms cut off young seedlings at ground level. They work at night, sometimes bore into the heads of mature plants.

Botanical pesticides are special because it can be produced easily by farmers for sustainable agriculture and small industries (Roy *et al.* 2005). The control of insect pests in broccoli can be effectively controlled by different neem products such as leaf extracts, seed extracts, bark extracts, neem oil, neem powder etc. About 413 different species/sub-species of insect pest have been listed by Schmutterer, 1995 and found to be susceptible to neem products. The listed species/sub-species belongs to different insect orders most of them were Lepidoptera (136) and Coleopteran (79).

In Bangladesh, a few works found on the efficacy of botanical insecticides in broccoli field. For this reason, this study was undertaken to evaluate insect incidence and ecofriends management using neem products in broccoli field.

Objectives

To fulfill of the study following objectives were undertaken:

- To determine the incidence and damage severity of different insect pests on broccoli.
- To find out the efficacy of different neem products against insect pests of broccoli.

CHAPTER II

REVIEW OF LITERATURE

In Bangladesh, broccoli is a minor but become an important vegetable crop, but the crop cultivation faces various problems including the insect pest infestation and their management. An attempt has been taken in this chapter to review the pertinent research work related to the present study. The information is given below under the following sub-headings:

2.1. General review of insect pest of broccoli

2.1.1. Cabbage worm (*Pieris rapae*)

The term cabbage worm is primarily used for any of four kinds of lepidopteran whose larvae feed on cabbages and other cole crops. Favorite foods include broccoli, cauliflower, brussels sprouts, collards, kale, mustard greens, turnip greens, radishes, turnips, rutabagas and kohlrabi. This small group of similar pest species is known to agriculturists as the cabbage worm complete butterflies.

Nature of damage

Larvae of *Pieris rapae* damage cruciferous crops by chewing leaves, hearts and curds. Young larvae hatch on the outer leaves and feed on them superficially leaving the upper leaf surface intact. Older larvae make holes in the leaves and are more likely to eat through small veins, they also damage the outer leaves of the hearts of cabbages or the curd of broccoli or cauliflowers. They often bore into the center of the head damaging the edible portion of the plant. Heavily infested plants become ragged and stunted but no webbing occurs. The presence of masses of wet greenish-brown excrement deep among leaves is indicative of this pest. In large infestations of *P.*

rapae the plant may be reduced to a partial or complete skeleton, in which all the leaf tissue except the veins has been eaten (CABI 2021, Hely *et al.* 1982).

2.1.2. Diamondback moth (*Plutella xylostella*)

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

Nature of damage

Diamondback moth (DBM) makes numerous small holes in the leaves, and sometimes leaves fine webbing in the center of the plant at its larval stage. Foliar injury lowers the quality of the crop, and weakens the plant. The larvae themselves can be a contaminant of the final product like pests of cabbage. It usually devours only a small portion of leaf. Larvae work on the underside and eat many small holes. Frequently they leave only the upper epidermis, which has an isinglass-like effect (Janmaat 2003).

Walsh and Furlong (2008) reported that, from May to September, *Plutella xylostella* (L.) (diamondback moth) poses the greatest threat to production.

2.1.3. Cabbage semi looper (*Sopodoptera litura*)

The cabbage semi-looper (*Sopodoptera litura*) is a member of the moth family Noctuidae belongs to the order of Lepidoptera. It is found throughout the southern palaearctic ecozone, all of North America, part of Africa and most of the Oriental and Indo-Australian region.

Nature of damage

Capinera (1999a) reported that, the larvae of cabbage semi-looper 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.

2.1.4. Cutworm (*Agrotis ipsilon*)

Cutworms are the larvae of several species of night-flying moths (Order- Lepidoptera, Family- Noctuidae).

Nature of damage

Bentley *et al.* (1996) conducted a study and reported that, cutworms are common pest of many vegetable crops including carrots, celery, lettuce, onion, tomato, pepper, eggplant, cole crops, rutabaga, beans, cucurbit crops, sweet corn and several others. Most species of cutworms are solitary feeders found in the soil; however some species occasionally attack the foliage and/or fruit of some vegetable crops.

All instars of *Agrotis ipsilon* feed on the leaves of corn seedlings, but the most serious damage results from leaf and stem cutting by late instars (Clement and McCartney 1982).

Hahn and Burkness (2021) also found that, young larvae feed on the foliage or small roots of weeds or crops until they reach about 1/2 inch in length. At this stage, they can begin feeding on seedling stems, either cutting through them or burrowing into them. Corn, peppers, tomatoes, beans, and the crucifer family are common hosts, but they will attack many kinds of herbaceous plants.

Benssin (2011) observed in the study that, cutworms feed at night causing serious damage to stems and foliage of young plants. Stalks of plants may be cut. The variegated cutworm climbs the plants to feed on foliage and the bud.

2.1.5. Aphid (*Aphis* spp.)

Aphids are small sap-sucking insects and members of the superfamily Aphidoidea and family Aphididae. Common names include greenfly and blackfly, although individuals within a species can vary widely in color.

Nature of damage

The black bean aphid is a major pest of sugar beet, bean, and celery crops, with large numbers of aphids cause stunting of the plants. Beans suffer damage to flowers and pods which may not develop properly. Early-sown crops may avoid significant damage if they have already flowered before the number of aphids builds up in the spring (RIR 2013). Celery can be heavily infested. The plants are stunted by the removal of sap, the stems are distorted, harmful viruses are transmitted, and aphid residues may contaminate the crop (Godfrey and Trumble 2009). As a result of infestation by this aphid, leaves of sugar beet become swollen, roll, and cease developing. The roots grow poorly and the sugar content is reduced. In some other plants, the leaves do not become distorted, but growth is affected and flowers abort due to the action of the toxic saliva injected by the aphid to improve the flow of sap (HYPP 2013).

To obtain enough protein, aphids need to suck large volumes of sap. The excess sugary fluid, honeydew, is secreted by the aphids. It adheres to plants, where it promotes growth of sooty molds. These are unsightly, reduce the surface area of the plant available for photosynthesis and may reduce the value of the crop. These aphids are also the vectors of about 30 plant viruses, mostly of the non-persistent variety. The aphids may not be the original source of infection, but are instrumental in spreading the virus through the crop (RIR 2013).

2.1.6. Flea beetles (*Psylliodes chrysocephala*)

The flea beetle is a small, jumping beetle of the leaf beetle family (Chrysomelidae) that makes up the tribe Alticini which is part of the subfamily Galerucinae. Historically the flea beetles were classified as their own subfamily.

Nature of damage

The adults chew holes in the leaves. The larvae usually mine the lower petioles, moving from ageing to healthy tissue, but will move to the stem and destroy the growing point if larval numbers are large or if the rosette is poorly developed (Williams and Carden 1961, Bonnemaison and Jourdheuil 1954, Ebbe-Nyman 1952). Severe larval attack can distort the plant and cause the epidermis to peel, leading to the death of the plant (Williams and Carden 1961). As well as causing direct damage, attack by *Psylliodes chrysocephala* is associated with fungal (*Leptosphaeria maculans* and *Phoma lingam*) and bacterial (*Erwinia*) infection, (Nilsson 1990, Newman 1984, Williams and Carden 1961, Bonnemaison and Jourdheuil 1954). The beetle may transmit turnip crinkle virus (Bonnemaison 1965). Plants infested with the cabbage stem flea beetle are also more susceptible to frost damage (Winfield 1992).

The cabbage stem flea beetle is a pest of most brassica seed crops (Winfield 1992). It is a serious pest of winter rape in Sweden, France, Switzerland, the Netherlands and the UK (Bromand 1990). In the UK, it is the most important establishment pest of rape, leading to yield losses of up to 20% (Lane and Cooper 1989). Larval infestation causes an overall loss in vigour leading to lower yields even at very low larval densities (Nilsson 1990).

2.2. Management practices of insect pests of broccoli

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.

New plantings should be as far as possible from those of the previous season. At the end of the season crops should be harvested without delay and plant residues should be ploughed under or destroyed. Intercropping and trap crops have had limited success as methods of controlling *Pieris rapae* (Wiech 1996, Luther *et al.* 1996, Kenny and Chapman 1988). Both strategies are likely to have some value in IPM systems based on pesticides or natural enemies.

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 vegetables.

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 *Plutella 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

Bacillus 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 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 destroy or expose overwintering larvae or pupae (Hahn and Burkness 2021).

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 moth flying activity 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 to 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 transplants. 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 2021).

2.2.3. Chemical control

Insecticides have been used to control *Pieris rapae* since crucifers have been cultivated. Generally, insecticides have to be applied every one or two weeks to achieve good crop quality and this has led to numerous instances of insecticide resistance in *P. rapae* (Han *et al.* 1987, Chou *et al.* 1984). Pesticide applications should begin when the *P. rapae* population reaches a threshold of one larva per plant. Spraying should be repeated every 5-7 days as needed.

Various chemical treatments are available to kill the aphids and organic growers can use a solution of soft soap (Godfrey and Trumble 2009).

In controlling moths mostly are used organic phosphorus esters. In this group classified active compounds are chlorine pirifos-methil, phenitrotion and acephate (Pelosini 1999). Sufficient efficacy in this relation can attain also with pyrethroids (cypermethrin, deltamethrin, lambda-cyhalothrin, betacyfluthrin 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 controling eggs and young larvae (Corvi and Nardi 1998). If there are caterpillars of various developmental stages on the ground, Corvi and Nardi (1998) recommend the application of pyretroids 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) advice double treatment with synthetic insecticides (pyretroids, carbamates, organic phosphorus esters and growth regulators).

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® 20WDG) is a novel insecticide, representing the IRAC Mode of Action Group 28 (ryanodine receptor modulator) within the IRAC (Insecticide Resistance Action Committee) mode of action classification scheme. Flubendiamide is the first member of phthalic acid diamides, and is active against abroad 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 2021).

Because an autumn application of pyrethroid is relatively inexpensive, fields are often sprayed prophylactically against the cabbage stem flea beetle/aphids, even though treatment is rarely justified (Alford *et al.* 1991, Lane and Cooper 1989). In 1998, 37,686 ha were treated against beetle in the UK (Garthwaite and Thomas 1998). Five synthetic pyrethroids are currently recommended for use against the cabbage stem flea beetle in the UK (Whitehead 2000).

2.2.4. Biological control

Biological control includes use of natural enemies/biological control agents to regulate cabbage butterflies. Three well known biological control agents including *Bacillus thuringiensis* (Bt), entomopathogenic nematodes and wasps have a potential to manage cabbage butterfly population in the vegetable gardens and fields.

Chemical pest control agents are extensively used in all countries of the world but they are regarded as ecologically unacceptable. Therefore, there is an increased social pressure to replace them gradually with biopesticides which are safe to humans and non-target organisms. The harmful environmental implications of the synthetic chemicals have compelled to search for some alternative methods. This leads to increased development of compounds based on the models of naturally occurring toxins of biological origin, having various biological activities. Biopesticides include a broad array of microbial pesticides, biochemicals derived from micro-organisms and other natural sources, and processes involving the genetic modification of plants to express genes encoding insecticidal toxins. This review outlines the current state of knowledge on the potential use of biopesticides in global control of pests.

In order to develop sustainable pest management programs for *Brassica* crops, an effective biological control program for *P. xylostella* must be integrated with effective control measures for *C. pavonana* (e.g. selective insecticides, manipulation of endemic predator complexes, trap crops and other means of host plant manipulation). Biological control can form the foundation for IPM strategies for the management of *P. xylostella* and other crucifer pests (Furlong *et al.* 2008a) but in order to take this approach, a detailed understanding of pest and natural enemy ecology is required (Furlong *et al.* 2008b, Furlong and Zalucki 2007).

The program is based on a cost-effective crop scouting system and uses action thresholds for cabbage, broccoli and cauliflower. It includes a DBM insecticide resistance management strategy that emphasises the rotation of products with selective activity and different modes of action to maximise the impact of existing biological control agents (Walker *et al.* 2009).

In the 2009-10 year, weekly pheromone trap catches of DBM were compared with corresponding larval infestations in five crops. Results show that increases in DBM larval infestations were detected 1–3 weeks (most between 2 and 3 weeks) after increases in pheromone trap catches. These results indicate the potential of DBM pheromone trap monitoring as a pest management tool for forecasting damaging larval infestations in a cold-winter climate (Walker *et al.* 2011).

Classical biological control has been carried out in a number of countries using *Cotesia glomerata*, *Cotesia rubecula*, *Pteromalus puparum*, *Compsilura concinnata* or *Phryxe vulgaris*.

2.2.4.1. *Bacillus thuringiensis kurstaki* (Bt)

This bacterium is recognized as a bacterial insecticide but it is not harmful to the humans, animals or the environment. This is a very effective biopesticide on young larval stages as compared to the mature larval stages of cabbage lepidopterous insect pests.

This microbial biocontrol agent is commercially available and can be applied using traditional sprayers. For the effective control of cabbage lepidopterous insect pests, *Bacillus thuringiensis kurstaki* should be applied at every seven day interval after noticing the first incidence of pest.

Building on and expanding earlier work reported in (Grzywacz *et al.* 2010, Russell *et al.* 2008) reviewed current control methods for brassica pests in Asia and Africa and concluded that effective *Bt transgenics* could play a very useful role.

Bioassays with pure Cry1B and Cry1C proteins in India, USA, Australia, Indonesia, Taiwan and China (Shelton *et al.* 2009) using leaf dip assays showed the LC50 values for both Cry1B and Cry1C against diamondback moth to be <1.3 ppm in all field populations tested. *Crocidolomia binotalis* had LC50s of >1.07 ppm for Cry1B and <1.89 ppm for Cry1C. The prospects for control of these species with transgenic *Bt brassicas* was therefore good. However, *S. litura*, an increasing pest of brassicas in Asia showed less susceptibility with LC50s >10 ppm to both proteins (Russell *et al.* 2011).

2.2.4.2. Entomopathogenic nematodes

Currently, entomopathogenic nematodes are used as effective biological control agents against many different kinds of soil-dwelling insect pests of many economically important crops and turf grasses. These nematodes are commercially available and are not harmful to humans, animals and even beneficial insects like honeybees. Canadian researchers have demonstrated that the entomopathogenic nematodes including *Steinernema carpocapsae*, *S. feltiae* and *S. riobrave* can cause 76 to 100% mortality of cabbage butterfly *Artogeia rapae* if applied at temperatures ranging from 25 to 30°C and their LC50 values were ranged from 4 to 18 infective juveniles (Bélair *et al.* 2003). Mahar *et al.* (2005) also reported that in addition to the above stated species of entomopathogenic nematodes, *Heterorhabditis bacteriophora* and *H. indica* nematodes can infect and kill both larvae and pupae of cabbage butterflies. Recently, another insect-parasitic nematode, *Rhabditis blumi* also been shown to be effective against cabbage butterfly (Park *et al.* 2012).

The South American nematode *Steinernema scapterisci* kills *Neocapteriscus* mole crickets by introducing bacteria into their bodies, causing an overwhelming infection (Nguyen and Smart 1992a). *Steinernema neocurtillae* is native to Florida and attacks native *Neocurtilla hexadactyla* mole crickets (Nguyen and Smart 1992b).

An entomopathogenic nematode, *Steinernema scapterisci* Nguyen & Smart, was introduced from Uruguay in 1985 (Nguyen and Smart 1992). It is specific to mole crickets, persists readily under Florida's environmental conditions, and is dispersed by crickets. Field collections consistently show infection levels of 10% or greater (Parkman *et al.* 1993 a&b), and infected crickets die within 12 days.

Much use has been made of bacterial (primarily *Bacillus thuringiensis*) and viral biocides against *P. rapae* (Webb and Shelton 1991, Su 1991, 1989, 1986, Goral *et al.* 1984).

2.2.4.3. Parasitoid

Biever *et al.* (1994) developed a biological control system for *P. rapae* based on natural enemies for 53 hectares of cabbage in Texas. In Bermuda, a parasitic wasp, *Pteromallus puparum*, was introduced for control in 1987.

Trichogramma is a potential biological control agent against lepidopterous insect pest. It is an egg parasitoid that kills the pest before it can cause any damage to the plant. *Trichogramma* are among the smallest insects, having a wingspread of about 1/50th of an inch. Despite its size, this parasitic wasp is an efficient destroyer of the eggs of more than 200 species of moths and butterflies which are leaf eaters in the larval stage. *Trichogramma* wasps seek out eggs, but do not feed on or harm vegetation. It is a particularly effective control agent because it kills its host before a plant can be damaged.

The natural enemies including *Diadegma semiclausum, Cantheonidea furcellata* and *Erigonidium graminicola* and the cropping systems including rotating rice, corn and shallot in summer were effective in managing the Diamond back moth (Xia *et al.* 2011). The parasitoids *Diadegma* (for the highlands) and *Cotesia* (for the lowlands) were imported, mass reared and released in the field with almost 85% parasitization (Colting and Cardona 2011).

The larval parasitoids like ichneumonid, braconids etc. and the pupal parasitoids like *Diadromus collaris, Diadromus subtilicornis* etc. are the most effective natural enemies of *P. xylostella* (Karimzadeh and Wright 2008, Sarfraz *et al.* 2005 and Talekar and Shelton 1993).

Many studies revealed that different host-plant species or cultivars have differential effects on *P. xylostella* parasitism success by parasitoids, in particular, *Cotesia plutellae* (Kurdjumov) and *Diadegma semiclausum* (Hellen) (Karimzadeh and Wright 2008, Karimzadeh *et al.* 2004, Liu and Jiang 2003, Haseeb *et al.* 2001, Verkerke and Wright 1997, Talekar and Yang 1991).

A various species of parasitic wasps can serves as effective biological control agents against lepidopterous insect pests of cabbage. The egg parasitic wasp, *Trichogramma* *spp.* is the most effective egg parasitoid against lepidopterous insect pests of cabbage. Seven species of parasitoid wasps (five larval and two pupal parasitoids) and two species of hyperparasitoid wasps were determined. The parasitoids were included the braconids *Cotesia plutellae* (Kurdjumov), *Bracon hebetor* Say and *Apanteles* sp., the ichneumonid *Diadegma semiclausum* (Hellen), and the eulophid *Oomyzus sokolowskii* (Kurdjumov) as larval parasitoids, and the ichneumonids *Diadromus collaris* (Gravenhorst) and *Diadromus subtilicornis* (Gravenhorst) as pupal parasitoids. In addition, the pteromalids *Mokrzeckia obscura* Graham and *Pteromalus* sp. were identified as the hyperparasitoids (Afiunizadeh *et al.* 2011).

Microsporidium is a pathogenic parasite for many insects including lepidopteran pests. It is an obligatory in nature which has a wide distribution around the world. It has a big potential as a microbial pesticide or biopesticide agent for controlling insect populations (Sajap 2004).

Zainal- Abidin *et al.* (2004) named microsporidia isolated from Malaysia's *P. xylostella* as *Nosema bombycis* based on the morphological characters. Experimental studies have shown that this parasite can cause high mortality rates in DBM in particular the larval stages.

The only biological control program against *N. didactylus* was in Puerto Rico, and it succeeded in establishing the parasitoid wasp *Larra bicolor* from Amazonian Brazil (Wolcott 1941).

One introduced parasitoid is *Larra bicolor* Fabricius (Hymenoptera: Crabronidae), which was imported from Bolivia in 1981 and established in both southern and northern Florida, but seems to be constrained by availability of suitable adult food sources (nectar from flowers) in Florida (Frank *et al.* 1995).

Another parasitoid *Ormia depleta* (Wiedemann) (Diptera: Tachinidae), which was imported from Brazil in 1988, is attracted to the calls of male mole crickets. Its release has resulted in reduced mole cricket injury in southern Florida (Frank *et al.* 1996).

2.2.4.4. Botanical control

A botanical pesticide 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 property which include neem, sweetflag, cashew, custard apple, sugar apple, derris, lantana, tayanin, indian privet, agave, crow plant etc. 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.

Pyrethrins, 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 azedarach* 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 and (Schmutterer, 1995) found to be 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, was finally explained in 1985 by Kraus *et al.* and Bilton *et al.* (Figure 1).

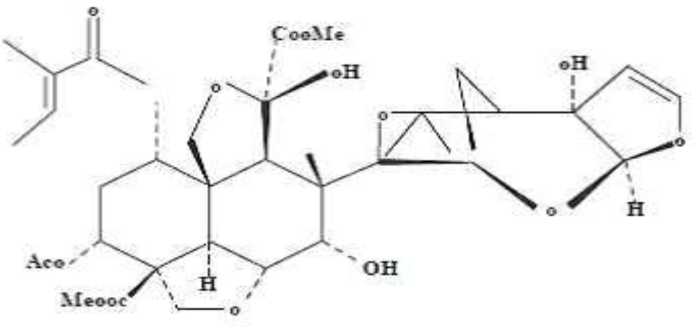


Figure 1. Structural formula of azadirachtin (Butterworth and Morgan 1968)

Azadirachtin is a limonoid alleliochemical (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. The leaves, which may also be used for various pest control.

Crude neem extracts deters settling and reduces feeding in *Myzus persicae* (Griffiths *et al.* 1989 and 1978).

The females of some lepidopterous insects are repelled by neem products on treated plant parts or other substrates and will not lay eggs on them under laboratory conditions.

It was reported that- against lemon butterfly *Papilio demoleus* 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 was 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 parts but 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 (Insect Growth Regulator) 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.

Botanicals possess an array of properties including insecticidal activity and insect growth regulatory activity against many insect pests and mites (Prakash *et al*. 1990, 1987, Rajasekaran and Kumaraswami 1985).

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 *Earias 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., *Earias vittella*, *Chilo partellus* Swinhoe, *Helicoverpa armigera* and *Spodoptera litura*.

65.7% reduction in bollworm infestation was observed in garlic treated plot. 10.3% bollworm incidence was observed with NSKE, datura and neem oil emulsion (Anonymous 1987).

Analysis of *Thuja occidentalis* L. as an 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%). When insects were treated with aromatized powder, significant differences were also found between treatments and control. Application of 100 mg of powder aromatized at 3 μL essential oil g^{-1} on bruchid pairs lead to 95% mortality of females and 100% of males with 0% of mortality in the control after 6 h exposure. Five days after their deposit, egg hatching was 1.2% (treated with kaolin powder aromatized with *T. occidentalis* essential oil), 41% (with kaolin alone) and 44% of eggs (control without kaolin). In the same experiment, adult emergence of 80% (in treatments with kaolin alone), 100% in control (without kaolin) and 0% (with kaolin aromatized with *T. occidentalis* essential oil) were recorded 30 days after treatment. Germination of cowpea seeds was 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).

For controlling cotton jassid Neem oil is used as a biopesticide (Koul *et al.* 2014).

2.2.6. IPM management

Naik *et al.* (2009) indicated that thiamethoxam @ 0.05% and combination treatments of thiamethoxam @ 0.0025% + novaluron @ 0.05% and thiamethoxam @ 0.0025% + azadirachtin @ 0.15% were highly effective in reducing population of *Amrasca bigutulla bigutulla* besides recording higher fruit yield of brinjal.

New plantings should be as far as possible from those of the previous season. At the end of the season crops should be harvested without delay and plant residues should be ploughed under or destroyed. Intercropping and trap crops have had limited success as methods of controlling *P. rapae* (Luther *et al.* 1996, Wiech 1996, Kenny and Chapman 1988). Both strategies are likely to have some value in IPM systems based on pesticides or natural enemies.

In recent years, good control has been achieved using managed spray or IPM programs (Ferguson and Barratt 1993, Stewart and Sears 1988, Leibee *et al.* 1984, Theunissen 1984). These generally combine close monitoring of pest and natural enemy populations with judicious applications of selective pesticides (Dornan *et al.* 1994, Endersby *et al.* 1992, Forster and Hommes 1992, Jackson 1982). Thresholds for chemical and/or biological control of *P. rapae* have been developed in a number of countries. In Canada, timing of an insecticide treatment based on an action threshold of one larva/plant (57% infestation), produced quality cabbage heads for storage or the fresh market. Treatment when an average of three larvae per plant (87% infestation) occurred, resulted in cabbages suitable for processing (Mailloux and Belloncik 1995).

CHAPTER III

MATERIALS AND METHOD

Though the incidence of insect pests in broccoli and their eco-friendly management using neem products is the main focus point of this present study which has been conducted during November 2019 to February 2020 in the experimental field of Sher-e-Bangla Agricultural University (SAU), Dhaka. Required materials and methodology are described below under the following sub-headings:

3.1. Location

The central field of the experimental farm of SAU, Dhaka was the location for this study at latitude 23.46 N and longitude 90.23 E with an elevation of 8.45 meter the sea level.

3.2. Climate

The experimental area is characterized by subtropical rainfall during the month of May to September and scattered rainfall during the rest of the year.

3.3. Soil

Soil of the experimental site was medium high land, clay loam in texture belonging to Agro-Ecological Zone of Madhupur tract (AEZ-28) with pH 5.8-6.5, CEC-25.28 (Haider *et al.*, 1991).

3.4. Land preparation

The soil was well prepared and good tilth ensured for commercial crop production. The target land was divided into 21 equal plots (3m×1m) with plot to plot distance was 0.50 m and block to block distance was 0.75 m. The land of the experimental field was ploughed with a power tiller. Later on the land was ploughed three times followed by laddering to obtain desirable tilth. The corners of the land were spaded and larger clods were broken into smaller pieces. After ploughing and laddering, all the stubbles and uprooted weeds were removed and then the land was ready. The field layout and design of the experiment were followed immediately after land preparation.

3.5. Manure and fertilizer

Recommended fertilizers were applied at the rate of 370 kg urea, 250 kg triple super phosphate (TSP) and 250 kg muriate of potash (MoP) per hectare were used as source of nitrogen, phosphorus and potassium, respectively. Moreover, well-decomposed cow dung (CD) was also applied at the rate of 10 ton/ha to the field at the time of land preparation (BARC 2012).

3.6. Design of experiment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The whole area of experimental field was divided into 3 blocks and each block was again divided into 7 unit plots. The size of the unit plot was 3 m×1 m. The block to block and plot to plot distance was 0.75m and 0.5m, respectively.

3.7. Collection of seed, seedling raising

The seeds of selected broccoli variety i.e. BARI broccoli 1 was collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. Before sowing, the germination test of seeds was done and on an average, 90% germination was found for these varieties. Seeds were then sown on the 7th November, 2019 in seed bed containing a mixture of equal proportion well decomposed cow dung and loam soil. After sowing seeds, the seedbeds were irrigated regularly. After germination, the seedlings were sprayed with water by a hand sprayer. Soil was spaded 3 or 4 days for a week.

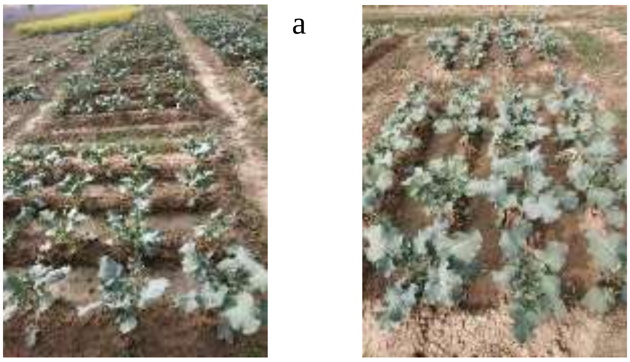
3.8. Seedling transplanting

The 30 days old healthy and uniform sized seedlings of broccoli variety were transplanted on December 6th, 2020 in the main field. Each plot contains 12 seedlings of broccoli with 2 rows followed by 50cm x 50cm (row to row and plant to plant distance, respectively).

Plate 1. Seedling transplanting

3.9. Cultural practices

After transplanting, a light irrigation was given. Subsequent irrigation was applied in all the plots as and when needed. Various intercultural operations like gap filling, weeding, earthen up, drainage etc. was done as and when necessary to cultivate broccoli.



a b

Plate 2. Irrigation in the main field (a & b)

3.10. Treatments

The experiment was evaluated to determine the incidence of insect pests in broccoli and their eco-friendly management using neem products. The treatments were used in this study are given bellow:-

Sl. No.	Treatments	Dose
1	Neem oil	5 ml/L at 7 days interval
2	Neem seed kernel	10g/L at 7 days interval
3	Neem seed extract	10ml/L at 7 days interval
4	Neem leaf extract	12 ml/L at 7 days interval
5	Neem bark extract	15ml/L at 7 days interval

6	Neem bark powder	15g/L at 7 days interval
7	Untreated Control	Spraying just water at 7 days interval

3.11. Treatment preparations

3.11.1. Neem oil as treament

The fresh neem oil was collected from Chawkbazar, Dhaka and the trix liquid detergent was collected from the local market of Agargoan bazaar, Dhaka. For neem oil application, 25 ml neem oil (@ 5.0 ml/L of water was used. The mixture was sprayed on the upper and lower surface of the plants of the treatment until the drop run off from the plant.

3.11.2. Neem seed kernel as treatment

The mature and dried neem seeds were collected from the neem tree found in the Horticulture Garden of SAU. Then seeds were roasted by electric oven. Then the seed kernel was separated and taken into the electric blender for blending. 500 gm of neem seed kernel powder was taken and stored for spraying in the field when necessary.

3.11.3. Neem seed extract as treatment

The mature and dried neem seeds were collected from the neem tree found in the Horticulture Garden of SAU. Then seeds were roasted by electric oven. Then the seed kernel was separated and seeds were taken into the electric blender for blending. 500 gm of blended neem seed was taken into a 1000 ml beaker and 500 ml water was added into the beaker. Then the beaker was shaken by electric stirrer for mixing up thoroughly the mixture. The aqueous mixture then filtered using Whatmen paper filter and preserved the aqueous extracts of neem seed kernel in the refrigerator at 4^0c for spraying in the field.

3.11.4. Neem leaf extract as treatment

The fresh neem leaves were collected from the neem tree found in the Horticulture Garden of SAU. Leaves were sun dried and crashed using electric grinder, of which

500 gm dried neem leaf powder was taken into a 1000 ml beaker. 500 ml water was taken into the beaker and then the beaker was shaken with the magnetic stirrer to make the extracts of neem leaves. The aqueous extract then filtered using Whatmen paper filter and preserved the aqueous extracts of neem leaf in the refrigerator at 4^0c for spraying in the field.

3.11.5. Neem bark extract as treatment

The thick bark were collected from the mature and old neem tree found in the Horticulture Garden of SAU. Then barks were roasted by electric oven. Then the barks were taken into the electric blender for blending. 500 gm of neem seed kernel powder was taken and stored for spraying in the field when necessary.

3.11.6. Neem bark powder as treatment

The thick bark were collected from the mature and old neem tree found in the Horticulture Garden of SAU. Then barks were roasted by electric oven. Then the barks were taken into the electric blender for blending. 500 gm of blended neem bark was taken into a 1000 ml beaker and 500 ml water was added into the beaker. Then the beaker was shaken by electric stirrer for mixing up thoroughly the mixture. The aqueous mixture then filtered using Whatmen paper filter and preserved the aqueous extracts of neem seed kernel in the refrigerator at 4^0c for spraying in the field.

3.12. Treatment application

T_1: Neem oil @ 5.0 ml/L of water was sprayed at 7 days interval. Under this treatment, neem oil was applied @ 25 ml /5L of water mixed with detergent @ 15 ml (1%) to make the oil easy soluble in water. After proper shaking, the prepared spray was applied with a high volume knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_2: Neem seed kernel @ 10.0 g/L of water was sprayed at 7 days interval. Under this treatment, neem seed kernel was applied @ 50g/5L of water. After proper shaking, the prepared spray was applied with a high volume knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_3: Neem seed extract @ 10.0 ml/L of water was sprayed at 7 days interval. Under this treatment, neem seed extract was applied @ 50ml/5L of water mixed with detergent @ 50 ml (1%) to make the oil easy soluble in water. After proper shaking, the prepared spray was applied with a high volume knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_4: Neem leaf extract @ 12.0 ml/L of water was sprayed at 7 days interval. Under this treatment, neem leaf extract was applied @ 60ml/5L of water mixed with detergent @ 50 ml (1%) to make the oil easy soluble in water. After proper shaking, the prepared spray was applied with a high volume knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_5: Neem bark extract @ 15.0 ml/L of water was sprayed at 7 days interval. Under this treatment, neem bark extract was applied @ 75ml/5L of water mixed with detergent @ 50 ml (1%) to make the oil easy soluble in water. After proper shaking, the prepared spray was applied with a high volume knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_6: Neem bark powder @ 15.0 g/L of water was sprayed at 7 days interval. Under this treatment, neem bark powder was applied @ 60g/5L of water mixed thoroughly. After proper shaking, the prepared spray was applied with a high volume knap-sack sprayer at 7 days intervals commencing from 20 DAT.

T_7: Untreated control which was sprayed @ 5L of water to the broccoli plots.

3.13. Data collection

For data collection five plants per plot were randomly selected and tagged. Data collection was started at vegetative stage to broccoli head harvest. The following parameters were considered during data collection.

3.13.1. Number of insect pests of broccoli and number of infested leaves caused by different insect pests

Plate 3. Data collection

Data were collected on the number of cabbage worm, diamondback moth, cabbage semi-looper, aphid, cutworm and flea beetle; number of infested leaves caused by cabbage worm, diamondback moth, aphid and flea beetle randomly selected 5 tagged plants per plot and counted separately for each treatment.

a b c

Plate 4: a. Aphid infested leaf, b. Caterpillar infested plant, and c. Caterpillar infested leaf

3.13.2. Number of infested plants by cutworm

Data were collected on the number of infested plants by cutworms per plot and counted separately for each treatment.

3.13.3. Card

Data were collected on the number of healthy and infested broccoli head per plot which was harvested at fully mature head stage of broccoli

Plate 5. Healthy card of broccoli

and weighted separately for each treatment.

3.14. Calculation

3.14.1. Percent of infested leaves by insect pests of broccoli

Number of infested leaves was counted from total leaves per five plants and percent leaf infestation by insect pests of broccoli were calculated as follows:

$$\% \text{ infested leaves} = \frac{\text{Number of infested broccoli leaves}}{\text{Total number of broccoli leaves}} \times 100$$

3.14.2. Percent cutworm infested plant

Number of infested plants was counted from total plants per plot and percent plant infestation by Cutworm was calculated as follows:

$$\% \text{ infested plants} = \frac{\text{Number of infested broccoli plants}}{\text{Total number of broccoli plants}} \times 100$$

3.14.3. Percent head infestation by number

Infested broccoli heads were counted from total harvested and the percent broccoli head infestation was calculated using the following formula:

$$\% \text{ Head infestation (number)} = \frac{\text{Number of infested broccoli head}}{\text{Total number of broccoli head}} \times 100$$

3.14.4. Percent broccoli head infestation by weight

Weight of the infested broccoli heads were recorded from total weight of the harvested broccoli heads and the percent broccoli head infestation by weight was calculated using the following formula:

$$\% \text{ Head infestation (weight)} = \frac{\text{Weight of the infested head}}{\text{Total weight of head}} \times 100$$

3.14.5. Percent reduction of broccoli head infestation over control

The number and weight of infested broccoli head and total broccoli head for each treated plot and untreated control plot were recorded and the percent reduction of broccoli head infestation in number and weight was calculated using the following formula:

$$\% \text{ Head infestation reduction over control} = \frac{X_2 - X_1}{X_2} \times 100$$

Where, X_1 = the mean value of the treated plot

X_2 = the mean value of the untreated plot

3.15. Statistical analysis

Data statistically analyzed through MSTAT-C software followed Randomized Complete Block Design and Duncan's multiple range tests was used to determine the incidence and damage assessment of insect pests of broccoli.

CHAPTER IV
RESULTS AND DISCUSSION

The study was conducted to evaluate the incidence of insect pests in broccoli and their eco-friendly management using neem products in the field under the Department of Entomology of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2019 to February 2020. The results have been presented and discussed, and possible interpretations have been given under the following sub-headings:

4.1. Incidence of different insect pests of broccoli

4.1.1. Cabbage worm

The significant variations were observed among different treatments in terms of the number of cabbage worm per five tagged plants of broccoli at different days after transplanting (DAT). In case of 30 DAT, the lowest number of cabbage worm was recorded in T_1 (2.56 cabbage worm/five tagged plants), which was statistically similar with T_4 (2.89) and followed by T_2 (3.33) and T_3 (3.67). On the other hand, the highest number of cabbage worm was recorded in T_7 (4.98 cabbage worm/five tagged plants), which was statistically similar with T_5 (4.67) and followed by T_6 (4.27 cabbage worm/five tagged plants) (Table 1). More or less similar trend was found in 40 DAT and 50 DAT.

In case of average, the lowest number of cabbage worm was recorded in T_1 (1.73 cabbage worm/five tagged plants), which was statistically different from other treatments and followed by T_4 (2.36), T_2 (2.68) and T_3 (3.08). On the other hand, the highest number of cabbage worm was recorded in T_7 (5.36 cabbage worm/five tagged plants), which was statistically different from other treatments and followed by T_5 (4.04) and T_6 (3.61 cabbage worm/five tagged plants) (Table 1).

Table 1: Effect of different treatments on number of cabbage worm per five tagged plants of broccoli at the different days after transplanting (DAT)

Treatments	No. of cabbage worm per 5 tagged plants per plot			
	30 DAT	**40 DAT**	**50DAT**	**Average**
T_1	2.56 e	1.87 f	0.76 f	1.73 f
T_2	3.33 cd	2.76 de	1.96 de	2.68 de
T_3	3.67 c	3.12 bc	2.46 cd	3.08 cd
T_4	2.89 de	2.43 ef	1.76 e	2.36 e
T_5	4.67 ab	4.23 b	3.21 b	4.04 b
T_6	4.27 b	3.67 bc	2.89 bc	3.61 bc
T_7	4.98 a	5.23 a	5.87 a	5.36 a
LSD (0.05)	0.55	0.58	0.66	0.59
CV (%)	8.51	10.16	14.22	10.51

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the number of cabbage worm per five tagged plants than the others. As a result, the order of rank of efficacy of the treatments applied against incidence of cabbage worm in terms of reducing the number of cabbage worm per five tagged plants was $T_1 < T_4 < T_2 < T_3 < T_6 < T_5 < T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against cabbage worm.

4.1.2. Diamondback moth

The significant variations were observed among different treatments in terms of the number of diamondback moth caterpillar per five tagged plants of broccoli at different days after transplanting. In case of 30 DAT, the lowest number of diamondback moth caterpillar was recorded in T_1 (2.78 diamondback moth caterpillar/five tagged plants), which was statistically similar with T_4 (3.31) and followed by T_2 (3.76) and T_3 (4.67). On the other hand, the highest number of diamondback moth caterpillar was recorded in T_7 (5.56 diamondback moth caterpillar/five tagged plants), which was statistically similar with T_5 (5.12) and T_6 (4.98 diamondback moth caterpillar/five tagged plants) (Table 2). More or less similar trend was found in 40 DAT and 50 DAT.

In case of average, the lowest number of diamond back moth caterpillar was recorded in T_1 (1.59 diamondback moth caterpillar/five tagged plants), which was statistically different from other treatments and followed by T_4 (2.55), T_2 (3.19) and T_3 (3.80). On the other hand, the highest number of diamondback moth caterpillar was recorded in T_7 (6.54 diamondback moth caterpillar/five tagged plants), which was statistically different from other treatments and followed by T_5 (4.23) and T_6 (4.00 diamondback moth caterpillar/five tagged plants) (Table 2).

Table 2: Effect of different treatments on the number of diamondback moth caterpillar per five tagged plants of broccoli at the different DAT

Treatments	No. of diamondback moth caterpillar per 5 tagged plants per plot			
	30 DAT	**40 DAT**	**50DAT**	**Average**
T_1	2.78 d	1.33 d	0.67 d	1.59 e
T_2	3.76 c	3.13 c	2.67 bc	3.19 cd
T_3	4.67 b	3.87 b	2.86 b	3.80 bc
T_4	3.31 cd	2.46 c	1.87 c	2.55 d
T_5	5.12 ab	4.23 b	3.33 b	4.23 b
T_6	4.98 ab	4.11 b	2.92 b	4.00 b
T_7	5.56 a	6.27 a	7.78 a	6.54 a
LSD (0.05)	0.60	0.69	0.88	0.71
CV (%)	8.20	11.08	16.35	11.25

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the number of diamondback moth per five tagged plants than the others. As a result, the order of rank of efficacy of the treatments applied against incidence of diamondback moth in terms of reducing the number of diamondback moth per five tagged plants was $T_1 < T_4 < T_2 < T_3 < T_6 < T_5 < T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against diamondback moth.

4.1.3. Cabbage semi-looper

The significant variations were observed among different treatments in terms of the number of cabbage semi-looper per five tagged plants of broccoli at different days after transplanting. In case of 30 DAT, the lowest number of cabbage semi-looper was recorded in T_1 (1.96 cabbage semi-looper/five tagged plants), which was statistically similar with T_4 (2.23) and followed by T_2 (2.67) and T_3 (2.89). On the other hand, the highest number of cabbage semi-looper was recorded in T_7 (4.13 cabbage semi-looper/five tagged plants), which was statistically similar with T_5 (3.89) and T_6 (3.33 cabbage semi-looper/five tagged plants) (Table 3). More or less similar trend was found in 40 DAT and 50 DAT.

In case of average, the lowest number of cabbage semi-looper was recorded in T_1 (1.17 cabbage semi-looper/five tagged plants), which was statistically similar with T_4 (1.48), T_2 (1.86) and followed by T_3 (1.99). On the other hand, the highest number of cabbage semi-looper was recorded in T_7 (5.07 cabbage semi-looper/five tagged plants), which was statistically different from other treatments and followed by T_5 (2.87) and T_6 (2.48 cabbage semi-looper/five tagged plants) (Table 3).

Table 3: Effect of different treatments on number of cabbage semi-looper per five tagged plants of broccoli at different DAT

Treatments	No. of cabbage semi-looper per 5 tagged plants per plot			
	30 DAT	40 DAT	50DAT	Average
T_1	1.96 e	1.11 f	0.43 d	1.17 e
T_2	2.67 cd	1.87 de	1.03 c	1.86 de
T_3	2.89 bc	1.96 cd	1.13 c	1.99 d
T_4	2.23 de	1.33 ef	0.87 c	1.48 ef
T_5	3.89 a	2.76 b	1.96 b	2.87 b
T_6	3.33 b	2.47 bc	1.65 b	2.48 c
T_7	4.13 a	4.96 a	6.13 a	5.07 a
LSD (0.05)	0.45	0.55	0.33	0.39
CV (%)	8.86	13.68	10.36	9.33

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the number of cabbage semi-looper per five tagged plants than the others. As a result, the order of rank of efficacy of the treatments applied against incidence of cabbage semi-looper in terms of reducing the number of cabbage semi-looper per five tagged plants was $T_1 < T_4 < T_2 < T_3 < T_6 < T_5 < T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against cabbage semi-looper.

4.1.4. Aphid

The significant variations were observed among different treatments in terms of the number of aphid per five tagged plants of broccoli at different days after transplanting. In case of 30 DAT, the lowest number of aphid was recorded in T_1 (1.78 aphid/five tagged plants), which was statistically similar with T_4 (2.23) and followed by T_2 (2.87) and T_3 (3.46). On the other hand, the highest number of aphid was recorded in T_7 (4.19 aphid/five tagged plants), which was statistically similar with T_5 (3.92) and T_6 (3.78 aphid/five tagged plants) (Table 4). More or less similar trend was found in 40 DAT and 50 DAT.

In case of average, the lowest number of aphid was recorded in T_1 (1.16 aphid/five tagged plants), which was statistically similar with T_4 (1.47) and followed by T_2 (1.73) and T_3 (2.33). On the other hand, the highest number of aphid was recorded in T_7 (5.70 aphid/five tagged plants), which was statistically different from other treatments and followed by T_5 (2.95) and T_6 (2.67 aphid/five tagged plants) (Table 4).

Table 4: Effect of different treatments on the number of aphid per five tagged plants of broccoli at different DAT

Treatments	No. of aphid per 5 tagged plants per plot			
	30 DAT	40 DAT	50DAT	Average
T_1	1.78 d	1.03 c	0.67 d	1.16 e
T_2	2.87 c	1.33 c	0.98 cd	1.73 d
T_3	3.46 b	2.43 b	1.09 cd	2.33 c
T_4	2.23 d	1.29 c	0.89 cd	1.47 de
T_5	3.92 ab	2.86 b	1.56 b	2.78 b
T_6	3.78 ab	2.67 b	1.21 bc	2.55 bc
T_7	4.19 a	5.78 a	7.12 a	5.70 a
LSD (0.05)	0.47	0.66	0.40	0.43
CV (%)	8.65	15.59	12.26	9.89

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the number of aphid per five tagged plants than the others. As a result, the order of rank of efficacy of the treatments applied against incidence of aphid in terms of reducing the number of aphid per five tagged plants was $T_1 < T_4 < T_2 < T_3 < T_6 < T_5 < T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against cabbage aphid.

4.1.5. Flea beetle

The significant variations were observed among different treatments in terms of the number of flea beetle per five tagged plants of broccoli at different days after transplanting. In case of 30 DAT, the lowest number of flea beetle was recorded in T_1 (1.46 flea beetle/five tagged plants), which was statistically similar with T_4 (1.89) and followed by T_2 (2.36) and T_3 (2.89). On the other hand, the highest number of flea beetle was recorded in T_7 (4.21 flea beetle/five tagged plants), which was statistically similar with T_5 (3.89) and followed by T_6 (3.67 flea beetle/five tagged plants) (Table 5). More or less similar trend was found in 40 DAT and 50 DAT.

In case of average, the lowest number of flea beetle was recorded in T_1 (0.87 flea beetle/five tagged plants), which was statistically similar with T_4 (1.19) and followed by T_2 (1.46) and T_3 (1.74). On the other hand, the highest number of flea beetle was recorded in T_7 (5.70 flea beetle/five tagged plants), which was statistically different from other treatments and followed by T_5 (2.95) and T_6 (2.67 flea beetle/five tagged plants) (Table 5).

Table 5: Effect of different treatments on the number of flea beetle per five tagged plants of broccoli at different DAT

Treatments	**No. of flea beetle per 5 tagged plants per plot**			
	30 DAT	**40 DAT**	**50DAT**	**Average**
T_1	1.46 e	0.78 e	0.36 d	0.87 e
T_2	2.36 d	1.09 de	0.92 c	1.46 cd
T_3	2.89 c	1.21 de	1.11 c	1.74 c
T_4	1.89 de	0.89 de	0.78 cd	1.19 de
T_5	3.89 ab	2.95 b	2.01 b	2.95 b
T_6	3.67 b	2.46 c	1.89 b	2.67 b
T_7	4.21 a	5.83 a	7.07 a	5.70 a
LSD (0.05)	0.49	0.36	0.42	0.43
CV (%)	9.80	9.64	12.31	9.40

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the number of flea beetle per five tagged plants than the others. As a result, the order of rank of efficacy of the treatments applied against incidence of flea beetle in terms of reducing the number of flea beetle per five tagged plants was $T_1 < T_4 < T_2 < T_3 < T_6 < T_5 < T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against cabbage flea beetle.

4.2. Effect of the different treatments on leaf infestation of broccoli

The significant variations were observed among different treatments in terms of total number of leaves of broccoli. The highest number of leaves was recorded in T_1 (14.47 leaves/plants), which was statistically different from other treatments and followed by T_4 (12.23), T_2 (11.67) and T_3 (11.23). On the other hand, the lowest number of leaves was recorded in T_7 (8.67 leaves/plants), which was statistically different from other treatments and followed by T_5 (10.47) and T_6 (10.67 leaves/plants) (Table 6).

The significant variations were observed among different treatments in terms of the number of infested leaves of broccoli. The lowest number of infested leaves was recorded in T_1 (2.23 leaves/plants), which was statistically different from other treatments and followed by T_4 (3.47), T_2 (4.23) and T_3 (4.67). On the other hand, the highest number of infested leaves was recorded in T_7 (7.23 leaves/plants), which was statistically different from other treatments and followed by T_5 (6.23) and T_6 (5.67 leaves/plants) (Table 6).

So, the lowest percent of infested leaves was recorded in T_1 (15.41%), which was statistically different from other treatments and followed by T_4 (28.37), T_2 (36.25) and T_3 (41.59). On the other hand, the highest percent was recorded in T_7 (83.39%), which was statistically different from other treatments and followed by T_5 (59.50) and T_6 (53.14%) (Table 6).

In terms of percent reducing over control, T_1 showed the best performance (81.52%) followed by T_4 (65.98), T_2 (56.53), T_3 (50.13) and T_6 (36.28). On the other hand, the lowest performance was showed in T_5 (28.65%) (Table 6).

Table 6: Effect of different treatments on leaf infestation by the insect pests of broccoli per plants of broccoli

Treatments	Leaf infestation per plants per plot			
	Total leaves	Infested leaves	% leaf infestation	Reduction over control
T_1	14.47 a	2.23 g	15.41 g	81.52
T_2	11.67 bc	4.23 e	36.25 e	56.53
T_3	11.23 bc	4.67 d	41.59 d	50.13
T_4	12.23 b	3.47 f	28.37 f	65.98
T_5	10.47 c	6.23 b	59.50 b	28.65
T_6	10.67 bc	5.67 c	53.14 c	36.28
T_7	8.67 d	7.23 a	83.39 a	0
LSD (0.05)	1.46	0.19	1.67	-
CV (%)	7.57	2.34	8.36	-

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the leaf infestation caused by the insect pests of broccoli per five tagged plants than the others. As a result, the order of rank of efficacy of the treatments applied against the in sect pests of broccoli in terms of reducing leaf infestation caused by different insect pests of broccoli per five tagged plants was $T_1 > T_4 > T_2 > T_3 > T_6 > T_5 > T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against cabbage flea beetle.

4.3. Effect of treatments on plant infestation of broccoli

There was no significant variations among different treatments in terms of total number of plants of broccoli per plot. Because, each plot contain 12 plants as per recommended distance of plant to plant and row to row (Table 7). Cutworm affected plants were replaced and new seedlings were transplanted there.

The significant variations were observed among different treatments in terms of the number of infested plants of broccoli. The lowest number of infested plants was recorded in T_1 (4.00 plants/plot), which was statistically similar with T_4 (4.00) and followed by T_2 (5.00) and T_3 (5.00). On the other hand, the highest number of infested plants was recorded in T_7 (10.00 plants/plot) which was statistically different from other treatments and followed by T_5 (7.00) and T_6 (6.00 plants/plot) (Table 7).

So, the lowest percent of infested plants was recorded in T_1 (33.33%), which was statistically similar with T_4 (33.33) and followed by T_2 (41.67) and T_3 (41.67). On the other hand, the highest percent was recorded in T_7 (83.33%), which was statistically different from other treatments and followed by T_5 (58.33) and T_6 (50.00%) (Table 7).

In terms of percent reducing over control, T_1 showed the best performance (60.00%) followed by T_4 (60.00), T_2 (49.99), T_3 (49.99) and T_6 (40.00). On the other hand, the lowest performance was showed in T_5 (30.00%) (Table 7).

Table 7: Effect of different treatments on plant infestation by the insect pests of broccoli per plot

Treatments	Plant infestation per plot			
	Total plants	Infested plants	% plant infestation	Reduction over control
T_1	12.00 a	4.00 e	33.33 e	60.00
T_2	12.00 a	5.00 d	41.67 d	49.99
T_3	12.00 a	5.00 d	41.67 d	49.99
T_4	12.00 a	4.00 e	33.33 e	60.00
T_5	12.00 a	7.00 b	58.33 b	30.00
T_6	12.00 a	6.00 c	50.00 c	40.00
T_7	12.00	10.00 a	83.33 a	0
LSD (0.05)	0.00	0.26	2.20	-
CV (%)	0.00	2.64	2.64	-

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the plant infestation caused by the insect pests of broccoli per plot than the others. As a result, the order of rank of efficacy of the treatments applied against the insect pests of broccoli in terms of reducing plant infestation caused by different insect pests of broccoli per plot was $T_1 > T_4 > T_2 > T_3 > T_6 > T_5 > T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against insect pests of broccoli.

4.4. Cutworm infested seedlings

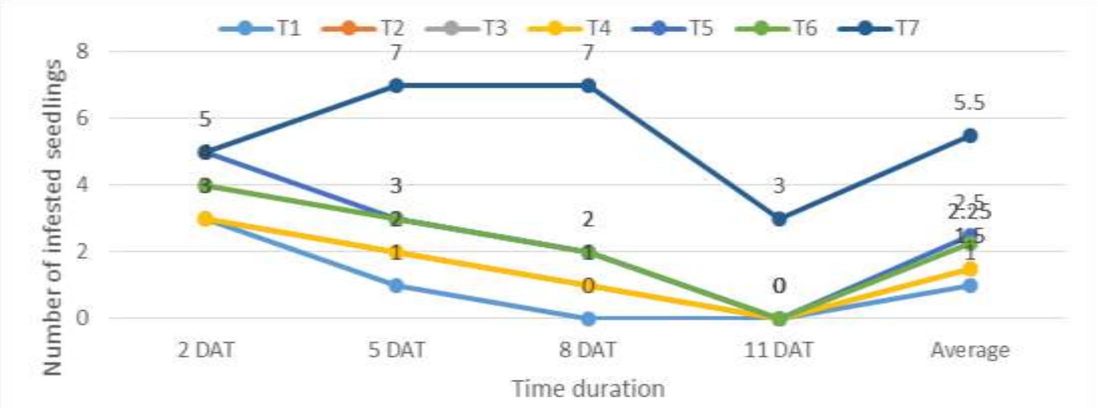


Figure 2: Effect of different treatments on seedling infestation caused by cutworm

From the findings it was revealed that the cutworm infestation on broccoli seedlings was ranged from 1 to 8 per plot in the field, where the lowest infestation was recorded in T_1 and highest in T_7. It was also observed that the cutworm infestation was started at 2 DAT in the broccoli field. The highest seedling infestation (5.00 seedlings/plot) was found in T_7 and T_5 and lowest (3.00 seedlings/plot) in T_1, T_4 and T_2. After treatment application the rate of seedling infestation reduced day by day and become zero infestation at 11 DAT in the broccoli field.

4.5. Effect of treatments on yield attributing characteristics of broccoli

Plant height (cm): The significant variations were observed among different treatments in terms of plant height of broccoli per plot. The highest plant height was recorded in T_1 (42.69 cm), which was statistically different from other treatments and followed by T_4 (39.46), T_2 (38.67) and T_3 (37.96). On the other hand, the lowest plant height was recorded in T_7 (35.43 cm), which was statistically similar with T_5 (36.57) and T_6 (37.63 cm) (Table 8).

Leaf length (cm): The significant variations were observed among different treatments in terms of leaf length of broccoli per plot. The highest leaf length was recorded in T_1 (40.12 cm), which was statistically similar with T_4 (38.78) and T_2 (37.29) and followed by T_3 (35.13). On the other hand, the lowest leaf length was recorded in T_7 (31.19 cm), which was statistically similar with T_5 (33.57) and T_6 (34.72 cm) (Table 8).

Leaf breadth (cm): The significant variations were observed among different treatments in terms of leaf breadth of broccoli per plot. The highest leaf breadth was recorded in T_1 (13.76 cm), which was statistically different from other treatments and followed by T_4 (12.33), T_2 (11.67) and T_3 (11.11). On the other hand, the lowest leaf breadth was recorded in T_7 (8.46 cm), which was statistically different from other treatments and followed by T_5 (9.67) and T_6 (10.56 cm) (Table 8).

Table 8: Effect of different treatments on plant height, leaf length and leaf breadth of broccoli per plot

Treatments	Yield attributing characteristics per plot		
	Plant height (cm)	**Leaf length (cm)**	**Leaf breadth (cm)**
T_1	42.69 a	40.12 a	13.76 a
T_2	38.67 bc	37.29 abc	11.67 bc
T_3	37.96 bc	35.13 bcd	11.11 cd
T_4	39.46 b	38.78 ab	12.33 b
T_5	36.57 bc	33.57 cd	9.67 e
T_6	37.63 bc	34.72 cd	10.56 d
T_7	35.43 c	31.19 d	8.46 f
LSD (0.05)	3.23	3.64	0.71
CV (%)	4.94	3.36	3.78

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in increasing plant height, leaf length and leaf breadth of broccoli per plot than the others. As a result, the order of rank of efficacy of the treatments applied against the insect pests of broccoli in terms of increasing plant height, leaf length and leaf breadth of broccoli per plot was $T_1 > T_4 > T_2 > T_3 > T_6 > T_5 > T_7$. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against insect pests of broccoli.

4.6. Effect of treatments on yield attributing characteristics of broccoli

Card height (cm): The significant variations were observed among different treatments in terms of card height of broccoli per plot. The highest card height was recorded in T_1 (22.11 cm), which was statistically similar with T_4 (20.78) and T_2 (19.46) and followed by T_3 (18.23). On the other hand, the lowest card height was recorded in T_7 (14.78 cm), which was statistically similar with T_5 (16.33) and T_6 (17.78 cm) (Table 9).

Card diameter (cm): The significant variations were observed among different treatments in terms of card diameter of broccoli per plot. The highest card diameter was recorded in T_1 (20.11 cm), which was statistically similar with T_4 (19.33) and T_2 (18.56) and followed by T_3 (17.89). On the other hand, the lowest card diameter was recorded in T_7 (16.78 cm), which was statistically similar with T_5 (16.98) and T_6 (17.46 cm) (Table 9).

Card perimeter (cm): The significant variations were observed among different treatments in terms of card perimeter of broccoli per plot. The highest card perimeter was recorded in T_1 (38.23 cm), which was statistically similar with T_4 (37.36) and T_2 (35.67) and followed by T_3 (34.13). On the other hand, the lowest card diameter was recorded in T_7 (29.98 cm), which was statistically similar with T_5 (32.56) and followed by T_6 (33.78 cm) (Table 9).

Table 9: Effect of different treatments on card height, card diameter and card perimeter of broccoli per plot

Treatments	**Yield attributing characteristics per plot**		
	Card height (cm)	**Card diameter (cm)**	**Card perimeter (cm)**
T_1	22.11 a	20.11 a	38.23 a
T_2	19.46 abc	18.56 abc	35.67 ab
T_3	18.23 bcd	17.89 bcd	34.13 bc
T_4	20.78 ab	19.33 ab	37.36 a
T_5	16.33 cd	16.98 cd	32.56 cd
T_6	17.78 bcd	17.46 cd	33.78 bc
T_7	14.78 d	16.78 d	29.98 d
LSD (0.05)	3.42	1.50	2.70
CV (%)	4.02	4.84	4.60

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in increasing card length, card diameter and card perimeter of broccoli per plot than the others. As a result, the order of rank of efficacy of the treatments applied against the insect pests of broccoli in terms of increasing card length, card diameter and card perimeter of broccoli per plot was T_1> T_4> T_2> T_3> T_6> T_5> T_7. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against insect pests of broccoli.

4.7. Effect of treatments on yield of broccoli

There was no significant variations among different treatments in terms of yield of broccoli. The highest yield was recorded in T_1 (16.23 t/ha), which was statistically similar with T_4 (15.89), T_2 (15.67), T_3 (15.43), T_6 (15.11), T_5 (14.78) and T_7 (14.36 t/ha) (Table 10).

Table 10: Effect of different treatments on yield of broccoli per plot

Treatments	Yield (kg/plot)	Yield (ton/ha)
T_1	10.67 a	16.23 a
T_2	9.09 b	15.67 a
T_3	8.87 b	15.43 a
T_4	9.23 ab	15.89 a
T_5	6.56 c	14.78 a
T_6	8.67 b	15.11 a
T_7	5.87 c	14.36 a
LSD (0.05)	1.482	4.16
CV (%)	7.01	5.97

[T_1: Neem oil @ 5 ml/L of water at 7 days interval; T_2: Neem seed kernel @ 10 ml/L of water at 7 days interval; T_3: Neem seed extract @ 10 ml/L of water at 7 days interval; T_4: Neem leaf extract @ 12 ml/L of water at 7 days interval; T_5: Neem bark extract @ 15 ml/L of water at 7 days interval; T_6: Neem bark powder @ 15 g/L of water at 7 days interval; T_7: Untreated control.]

From these above findings it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in increasing yield of broccoli than the others. As a result, the order of rank of efficacy of the treatments applied against the insect pests of broccoli in terms of increasing yield of broccoli was T_1> T_4> T_2> T_3> T_6> T_5> T_7. More or less similar research was also conducted by several researchers. Karim *et al.* (2007) evaluated the similar performance of neem oil against insect pests of broccoli.

4.8. Relationship between the percent of leaf infestation and yield of broccoli

Significant relationship was found between the percent of leaf infestation and yield of broccoli at different treatments when correlation was made between these two parameters. The highly significant ($p<0.05$), very strong (R^2=0.9824) and negative (slope =-0.0289) correlation was found between the percent leaf infestation and yield of broccoli, i.e. yield of broccoli decreased with the increase of the percent leaf infestation.

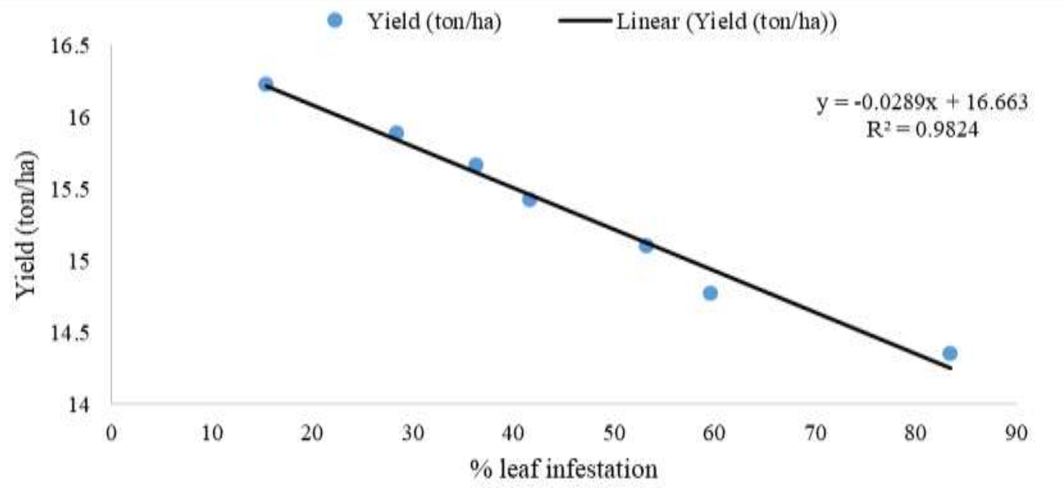


Figure 3: Relationship between percent leaf infestation and yield of broccoli

4.9. Relationship between the percent of plant infestation and yield of broccoli

Significant relationship was found between the percent of plant infestation and yield of broccoli at different treatments when correlation was made between these two parameters. The highly significant ($p<0.05$), very strong ($R^2=0.8853$) and negative (slope =-0.0347) correlation was found between the percent of plant infestation and yield of broccoli, i.e. yield of broccoli decreased with the increase of the percent plant infestation.

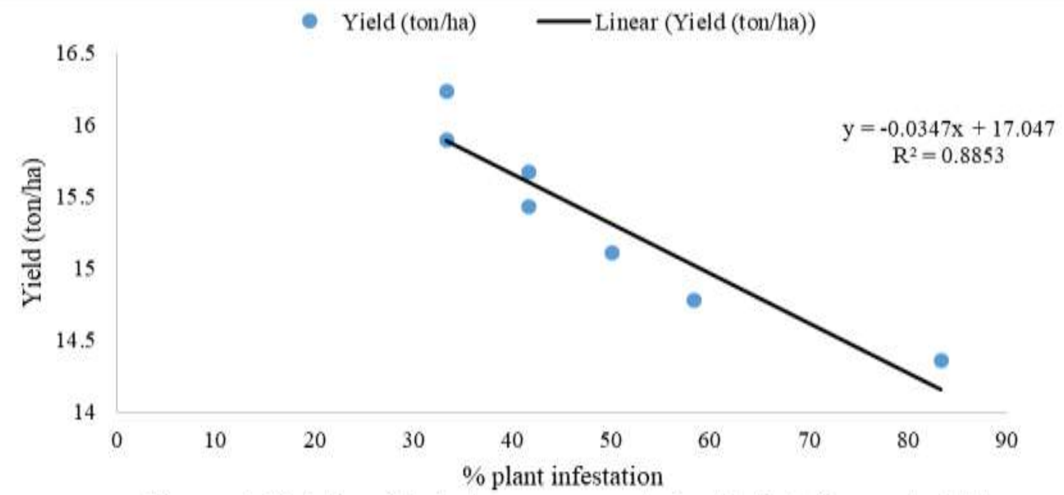


Figure 4: Relationship between percent plant infestation and yield of broccoli

4.10. Relationship between the card height and yield of broccoli

Significant relationship was found between the card height and yield of broccoli at different treatments when correlation was made between these two parameters. The highly significant ($p<0.05$), very strong (R^2=0.9857) and positive (slope =0.2556) correlation was found between the card height and yield of broccoli, i.e. yield of broccoli increased with the increase of the card height.

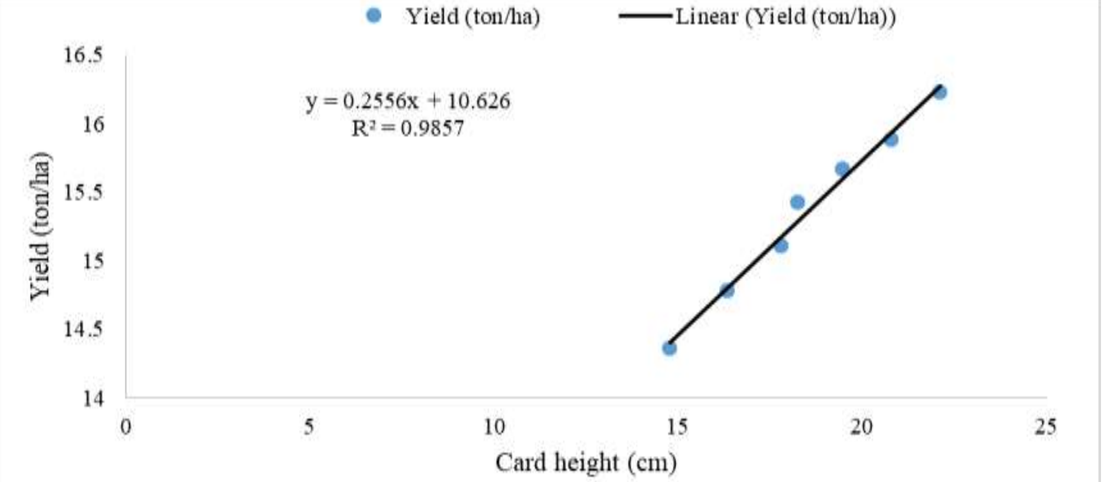


Figure 5: Relationship between card height and yield of broccoli

4.11. Relationship between the card diameter and yield of broccoli

Significant relationship was found between the card diameter and yield of broccoli at different treatments when correlation was made between these two parameters. The highly significant ($p<0.05$), very strong (R^2=0.9316) and negative (slope =0.5071) correlation was found between the card diameter and yield of broccoli, i.e. yield of broccoli increased with the increase of the card diameter.

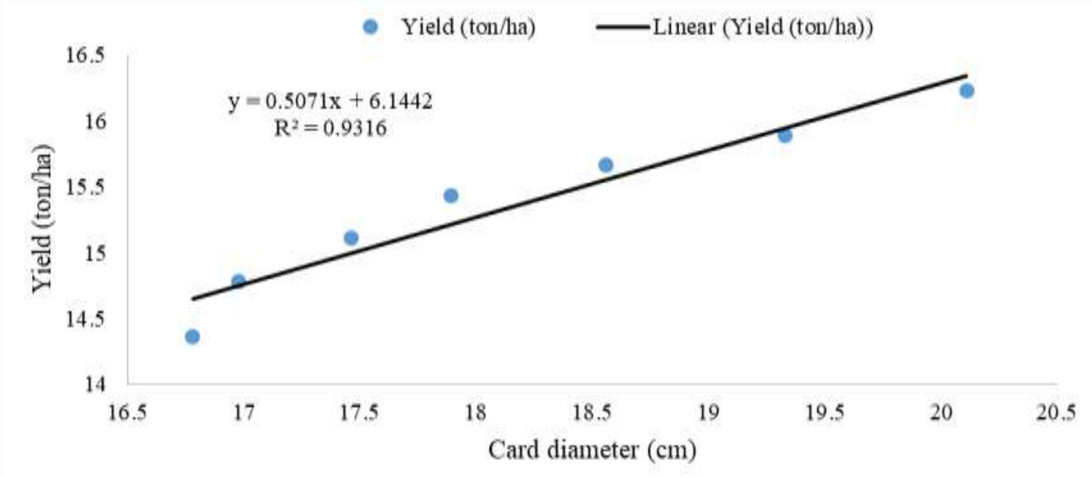


Figure 6: Relationship between card diameter and yield of broccoli

4.11. Relationship between the card perimeter and yield of broccoli

Significant relationship was found between the card perimeter and yield of broccoli at different treatments when correlation was made between these two parameters. The highly significant ($p<0.05$), very strong (R^2=0.9737) and positive (slope = 0.2262) correlation was found between the card perimeter and yield of broccoli, i.e. yield of broccoli increased with the increase of the card perimeter.

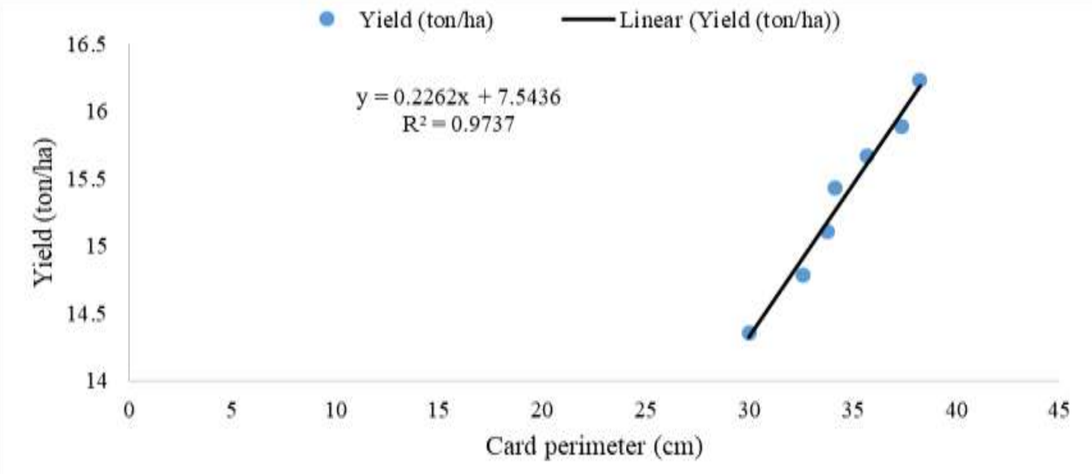


Figure 7: Relationship between card perimeter and yield of broccoli

CHAPTER V
SUMMARY AND CONCLUSION

The present experiment was conducted to study the incidence of insect pests in broccoli and their eco-friendly management using neem products during November 2019 to February 2020 at the central field of SAU, Dhaka, Bangladesh. The experiment comprised of seven different treatments (neem oil, neem seed kernel extract, neem seed extract, neem leaf extract, neem bark, extract, neem bark powder and untreated control). The experiment was laid out in Randomized Complete Block Design with three replications.

Among the different treatments T_1 comprised of Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the number of cabbage worm, diamondback moth caterpillar, cabbage semi-looper, aphid and flea beetle per five tagged plants. The order of rank of pest infestation was $T_1<T_4<T_2<T_3<T_6<T_5<T_7$.

Neem oil @ 5ml/L of water at 7 days interval (T1) showed the best performance in reducing the leaf infestation caused by the insect pests of broccoli as compared to other treatments.

Neem oil @ 5ml/L of water at 7 days interval showed the best performance in reducing the plant infestation caused by the insect pests of broccoli per plot as compared to others. The order of rank of efficacy of the treatments applied against the insect pests of broccoli was $T_1>T_4>T_2>T_3>T_6>T_5>T_7$.

Neem oil showed the best performance in increasing plant height, leaf length and leaf breadth of broccoli per plot than the others.

Neem oil also showed the best performance in increasing card length, card diameter and card perimeter of broccoli per plot than the others.

From this above study it was revealed that, among the different treatments T_1 comprised with Neem oil @ 5ml/L of water at 7 days interval showed the best performance in increasing yield of broccoli than the others. So the order of rank of efficacy of the treatments applied against the insect pests of broccoli of broccoli was $T_1>T_4>T_2>T_3>T_6>T_5>T_7$.

The conclusion of this study are presented below:

i. Broccoli was infested by cabbage worm, diamondback moth, cabbage semi-looper, aphid and flea beetle of broccoli.

ii. Neem oil played a vital role against the incidence of cabbage worm, diamondback moth, cabbage semi-looper, aphid and flea beetle and leaf and plant infestation by cabbage worm, diamondback moth, cabbage semi-looper, aphid and flea beetle of broccoli.

From this study some recommendations are given bellow:

i. Besides the bio pesticides used in this study other bio pesticides can be used against the incest pests of broccoli.

ii. Such kind of experiment should be taken at the different parts of the country.

CHAPTER VI

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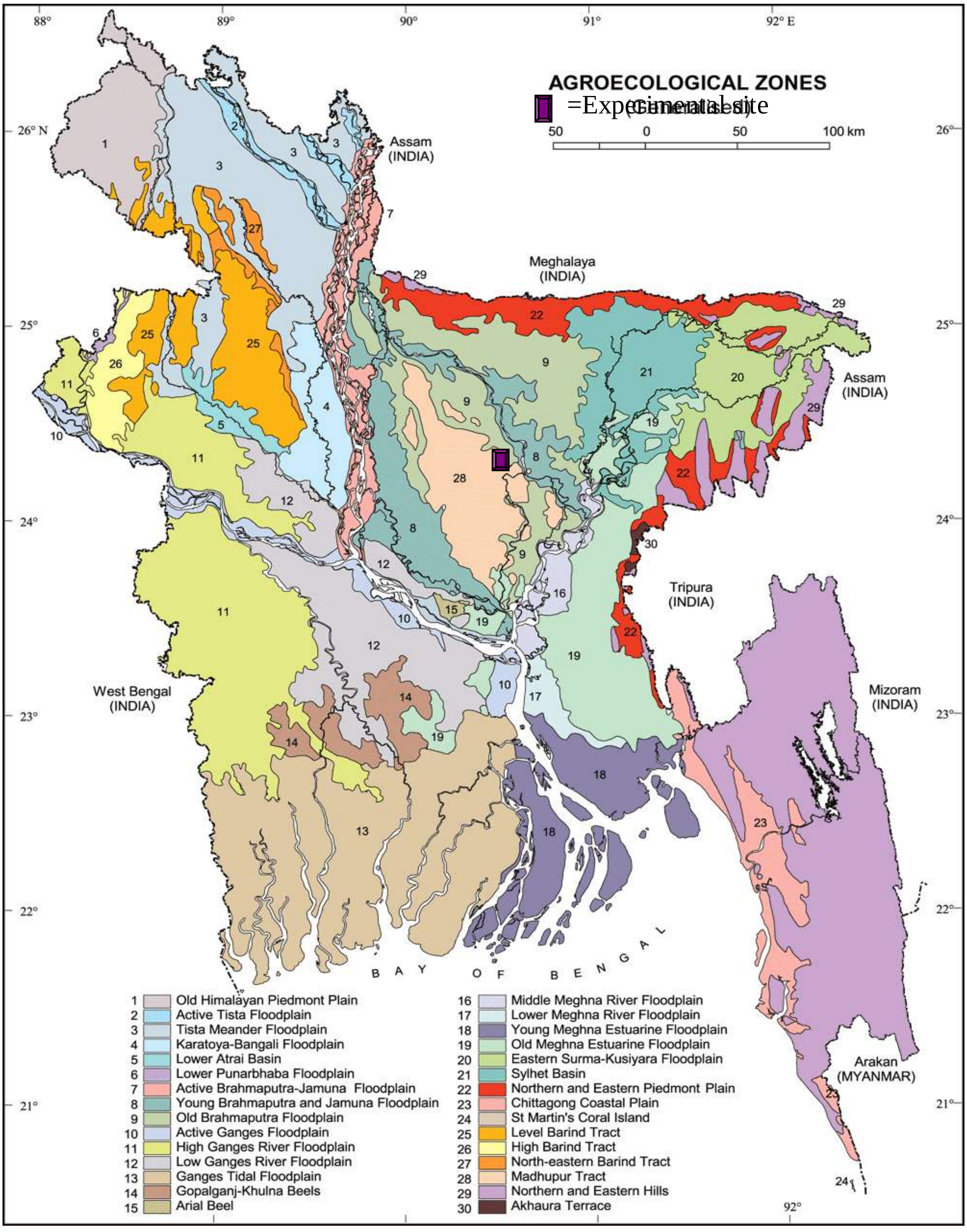
CHAPTER VII

APPENDICES

Appendix I. Experimental location on the map of Agro-ecological Zones of Bangladesh



Appendix II. The physical and chemical characteristics of soil of the experimental site as observed prior to experimentation (0-15 cm depth)

Constituents	Percent
Sand	26
Silt	45
Clay	29
Textural class	Silty clay

Chemical composition:

Soil characters	Value
Organic carbon (%)	0.45
Organic matter (%)	0.54
Total nitrogen (%)	0.027
Phosphorus	6.3 µg/g soil
Sulphur	8.42 µg/g soil
Magnesium	1.17 meq/100 g soil
Boron	0.88 µg/g soil
Copper	1.64 µg/g soil
Zinc	1.54 µg/g soil
Potassium	0.10 meg/100g soil

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