INSECT PESTS OF LETTUCE AND THEIR BIORATIONAL MANAGEMENT

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INSECT PESTS OF LETTUCE AND THEIR BIORATIONAL MANAGEMENT

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CERTIFICATE

This is to certify that the thesis entitled, **"INSECT PESTS OF LETTUCE AND THEIR BIORATIONAL MANAGEMENT"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in ENTOMOLOGY**, embodies the result of a piece of bona fide research work carried out by **Md. Obaidul Islam, Registration No. 19-10048** 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.

Date: June, 2021
Dhaka, Bangladesh

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INSECT PESTS OF LETTUCE AND THEIR BIORATIONAL MANAGEMENT

ABSTRACT

The experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from 10 November, 2019 to 20 February, 2020 to record the insect pests of lettuce and to evaluate their biorational management practices. The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. There were six treatments viz.; T_1= Abamectin @ 1.0 ml/L of water, T_2= *Bacillus thuringiensis* and abamectin @ 1.0 ml/L of water, T_3= Spinosad @ 0.5 ml/L of water, T_4= Azadirachtin @ 1.0 ml/L of water, T_5= Potassium salt of fatty acid @ 1.0 ml/L of water and T_6 = untreated control were used at 7 day interval. Flea beetle (*Monolepta signata* Olivier), Tobacco caterpillar (*Spdoptera litura* Fabricius), Aphid (*Lipaphis erysimi* Kaltenbach), Jute hairy caterpillar (*Spilosoma obliqua* Walker), Grasshopper (*Oxya velox* Fabricius) and Red pumpkin beetle (*Raphidopalpa foveicollis* Lucas) were recorded. The lowest percent of leaf infestation (10.70, 4.67, 4.76, 5.07, 5.03 and 8.74% respectively) of Flea beetle, Tobacco caterpillar, Aphid, Jute hairy caterpillar, Grasshopper and Red pumpkin beetle were observed in T_3 (Spinosad 45SC) treatments as against the highest (26.93, 18.81, 18.22, 37.67, 24.70 and 26.93%) was observed in T_6 treatment (untreated control). The highest single (0.91 kg plant^{-1}) and healthy plant weight (0.76 kg plant^{-1}) and highest yield (16.43 ton ha^{-1}) were observed in the same treatment (T_3). In contrast, the highest leaf infestation (21.50%), the lowest single plant weight (0.24 kg), healthy plant weight (0.29 kg plant^{-1}) and lowest total yield (7.08 ton ha^{-1}) were obtained from T_6 (untreated control). Spinosad 45SC @ 1.0 ml/L of water at 7 days interval gave the highest performance against insect pests of lettuce compared to all other treatments and may be used for the management insect pests of lettuce**.**

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ABBREVIATIONS AND ACRONYMS

% = Percentage

AEZ = Agro-Ecological Zone

BBS = Bangladesh Bureau of Statistics

cm = Centimeter

CV % = Percent Coefficient of Variation

DAT = Days After Transplanting

DMRT = Duncan's Multiple Range Test

e.g. = exempli gratia (L), for example

et al. = And others

etc. = Etcetera

FAO = Food and Agricultural Organization

g = Gram (s)

GM = Geometric mean

i.e. = id est (L), that is

Kg = Kilogram (s)

L = Litre

LSD = Least Significant Difference

M.S. = Master of Science

m^2 = Meter squares

mg = Mili gram

ml = MiliLitre

No. = Number

^0C = Degree Celceous

P = Phosphorus

SAU = Sher-e-Bangla Agricultural University

USA = United States of America

var. = Variety WHO = World Health Organization

µg = Microgram

CHAPTER I

INTRODUCTION

Lettuce, *Lactuca sativa* L., an annual leafy herb belongs to the family Compositae is one of the most popular salad crops and occupies the largest production area among salad crops in the world. It is the most popular amongst the salad vegetable crops (Squire *et al.* 1987). Lettuce is originated from Southern Europe and Western Asia (Rashid 1999). It mainly grows in temperate region and in some cases in the tropic and sub-tropic region of the world. Lettuce largely produced in greenhouse in temperate region (Lindquist 1960). Lettuce is getting popularity day by day but its production package is not much known to the Bangladeshi farmers. Insect pest infestation is a major problem of crop production in Bangladesh. It reduces yield and marketable quality of the produce and thereby farmers incur huge financial loss (Rashid 1993).

Cultivated lettuce is a self-fertilizing diploid species (2n=2x=18) from the Compositae family. Lettuce is the most popular, commercially produced leafy vegetable and is cultivated mainly in moderate climates in many countries around the world. Over 79% of the world production that totaled 24.3 million tons in 2018 (FAOSTAT 2018) originated from four countries: China, with 55.2% of the total production (by weight), the United States (16.0%), India (4.4%), and Spain (3.6%). Lettuce cultivars are divided into eight horticultural types on the basis of the shape and size of the head; the shape, size, and texture of leaves; stem length; and seed size. The leaves of crisp head (which includes two subtypes, iceberg and Batavia), romaine, butterhead, leaf, and Latin types are typically eaten fresh.

Lettuce is the leaf vegetable most consumed in the world and accounts for 50% of all domestic production and marketing of leafy greens. The two most consumed lettuce varieties are curly-leaf, representing over 50%, and iceberg, followed by smooth-leaf, mimosa, red, romaine and mini. Many insects attack this crop, impair the development of plants, affect the commercial aspect of leaves and spread several viral diseases. The aphids *Nasonovia ribisnigri* (Mosely), *Aulacorthum solani* (Kaltenbach), *Macrosiphum euphorbiae* (Thomas), and *Myzuspersicae* (Sulzer) are considered the most harmful to lettuce (Farsi *et al*. 2014 and Smith *et al*. 2008). The caterpillars *Spodoptera frugiperda* (Smith), *Trichoplusia ni* (Hübner), *Helicoverpa zea* (Boddie), *Heliothis virescens* (Fabricius) and *Agrotis ipsilon* (Hufnagel) have also been reported attacking lettuce plants (Imenes *et al*. 2000). Among other arthropods that attack lettuce are flea beetle, tobacco caterpillar, jute hairy caterpillar, aphid, grasshopper, green leaf eating caterpillar, red pumpkin beetle, white fly leaf-miner flies, some beetles, mole crickets, crickets, springtails, slugs and snails (Gomez-Polo 2014, Imenes *et al*. 2000).

Among the species considered lettuce pests, aphids (Hemiptera: Aphididae) and thrips (Thysanoptera: Thripidae) were the most frequent. Aphids were found in larger numbers, with 3,934 specimens (40.82%), followed by thrips with 1,094 specimens (11.35%) (Farsi *et al*. 2014, Saethre *et al*. 2011, Smith *et al*. 2008, Imenes *et al*. 2000). Seven species of aphids were identified associated with lettuce: *Aphis fabae, A. solani*, *M. euphorbiae, M. persicae*, *N. ribisnigri*, *Uroleucon ambrosiae* (Thomaz), and *Uroleucon sonchi* (Linnaeus). The species *N. ribisnigi*, *U. ambrosiae* and *U. sonchi* were the most frequently collected, contrary to the report of Santos *et al*. 1992.

In Bangladesh proper information about lettuce production is insufficient. The farmers of Bangladesh cultivate this crop by using their own knowledge due to the unavailability of instructions of standard production technique. As a result, they do not get satisfactory yield and return from investment. Insects that control the lettuce pests are included in many orders, including (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae), syrphid flies (Diptera: Syrphidae), flower bugs (Hemiptera: Anthocoridae) and parasitoids (Hymenoptera). There are also predatory mites (Acari: Phytoseiidae) and spiders (Arachnida) (Smith *et al*. 2008). The identification of species with the potential to be biological control agents of pests is necessary in an integrated pest management program. This can define which measures need to be adopted to promote the conservation and reproduction of these organisms, in order to reduce the use of chemicals in pest control.

Information on the insect species that occur in lettuce is essential for management strategies, since the correct taxonomic classification of pests allows the protection and the use of natural enemies more efficiently and consequently decreases pesticide use. Information on the fluctuation of pest and natural enemy populations is essential in an integrated pest management. Periods of highest pest infestation, distribution, and damage to plants associated with precipitation and temperature determine the suppression or growth of an insect population.

Considering the above factors, the present experiment was undertaken to study the following objectives;

- To identify the insect pests of lettuce and to select the major pests based on their extent of damage at different plant growth stage.
- To determine the efficacy of biorationals for the management of major insect pests of lettuce.

CHAPTER II

REVIEW OF LITERATURE

Lettuce is the leaf vegetable most consumed in the world and accounts for 50% of all domestic production and marketing of leafy greens. The two most consumed lettuce varieties are curly-leaf, representing over 50%, and iceberg, followed by smooth-leaf, mimosa, red, romaine and mini. Many insects attack this crop, impair the development of plants, affect the commercial aspect of leaves and spread several viral diseases. Information on the insect species that occur in lettuce is essential for management strategies, since the correct taxonomic classification of pests allows the protection and the use of natural enemies more efficiently and consequently decreases pesticide use. The aphids *Nasonovia ribisnigri* (Mosely), *Aulacorthum solani* (Kaltenbach), *Macrosiphum euphorbiae* (Thomas), and *Myzus persicae* (Sulzer) are considered the most harmful to lettuce (Farsi *et al*. 2014 and Smith *et al*. 2008). The caterpillars *Spodoptera frugiperda* (Smith), *Trichoplusia ni* (Hübner), *Helicoverpa zea* (Boddie), *Heliothis virescens* (Fabricius) and *Agrotis ipsilon* (Hufnagel) have also been reported attacking lettuce plants (Imenes *et al.* 2000, Santos *et al*. 1992). Among other arthropods that attack lettuce are flea beetle, tobacco caterpillar, jute hairy caterpillar, aphid, grasshopper, green leaf eating caterpillar, red pumpkin beetle, white fly leaf-miner flies, some beetles, mole crickets, crickets, springtails, slugs and snails (Gomez-Polo 2014, Imenes *et al*. 2000).

2.1. General review of insect pests of lettuce

2.2 Flea beetle

The flea beetle synonym is Leaf beetle. According to Ohno (1980) fifty thousand species of flea beetles distribute throughout the world. Only two species i.e; Stripped flea beetle (*Phyllotreta striolata*) and White-spotted flea beetle (*Monolepta signata*) classifications are given below as they were found in the research field during the experimental period.

2..2.1 Systematic position

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Chrysomelidae

Subfamily: Galerucinae

Tribe: Alticini

Genus: *Phyllotreta*

Species: *P. striolata* (Fabricus 1801)

Kingdom: Animalia

Phylum: Arthropoda

Class: Insrcta

Order: Coleoptera

Family: Chrysomelidae

Subfamily: Galerucinae

Tribe: Luperim

Genus: *Mololepta*

Species: *M. Signata* (Olivier 1808)

2.2.2 Origin and distribution

Flea beetles are thought to have been introduced from Eurasia. The crucifer flea beetle was first reported in the United States in 1923 (Bonnemaison 1965) and in Aggasiz, BC in the early 1920‘s (Burgess 1977a) while the striped flea beetle is thought to have been introduced into the United States in the 1700s (Bain and Le Sage 1998). According to Chamberlin and Tippins (1948) flea beetle was native to South America. But it was first reported in the United States in 1947 on young lettuce plants. It is now widely distributed in the southeastern United States with major field infestations reported in Alabama, Florida, Louisiana, Mississippi, South Carolina, and Texas (Rohwer *et al*. 1953, Oliver 1956, Balsbaugh 1978, Ameen and Story 1997a). Now it is found throughout the tropical and subtropical parts of the world. Fan and Huang (1991) included Phyllotreta species as serious pest in Taiwan. Flea beetles are commonly found in almost all kinds of habitats. The richest flea beetle communities occur in open spaces near forests or scrublands often associated with rivers or lakes and in various kinds of meadows and prairies. Density and species composition of phytophagous beetles are affected by many factors including vegetation, humidity, temperature and host plants (Konstantinov and Vandenberg 1996). The striped flea beetle i.e, *Phyllotreta striolata* is the most serious insect pests of canola. In North America, the striped flea beetle was reported from Carolina in 1801 and is now widespread across Canada, United States, Mexico and South America. In Hungary it is common of the leaf beetle assemblages in basswood and maple canopies, but only as visiting or tourist species (Van and Visser2007). Kimoto (2000) stated that the flea beetles are widely distributed to Holarctic region, India, Nepal, Thailand, Cambodia, Vietnam, China, Taiwan, Indonesia, Japan, Korea etc.

2.2.3 Biology and life cycle of the flea beetle

Despite of flea beetle economic importance and impact on vegetable production, very little research has been conducted on the biology and ecology of flea beetle. Most of the present information on the biology flea beetle was compiled from European literature since the species has been little investigated in North America. In the Europe, flea beetles over winters as adults which emerged at the end of March and the beginning of April when the temperature is 8-9 degrees Celsius. They search for appropriate host plants, and the feeding flea beetle is characterized by numerous small holes bordered by a narrow line of dead brown leaf (Jourdevil 1993). Both major species of flea beetles have one life cycle per calendar year, however, if the conditions are right, two cycles may be possible (Westdal and Romanow 1972). In Taiwan, *P. striolata* (Fabricius) is a notorious pest of cruciferous vegetables. Chen *et al.* (1990) published detailed information on its biology. Adults feed on the foliage of host plant and produce small round holes. The species is multivoltine and the larvae are generally root feeders. Pupation takes place in the soil. According to Whiting and Wilson (2002) flea beetles over winter as adults under soil and leaf litter in brushy or woody areas surrounding fields, rather than in grassy areas right next to fields. They emerge in early spring when temperatures reach about 50 degrees, feeding on weeds or crops, if available. Females soon lay their eggs in the soil at the base of these plants. Eggs hatch in a week or two and the larvae feed on plants until fully grown. Then they pupate in the soil for 11 to 13 days before emerging as adults. Delaying the planting dates of susceptible crops until after the over wintering beetles have emerged is one way to reduce damage to young plants. *Phyllotreta sp.* overwinters as adults in the soil or leaf litter near damaged cruciferous fields. Early in the spring, the beetles emerge from hibernation sites and feed on leaves of various cruciferous weeds. Later, they migrate to the seedlings of newly planted crops for further feeding (Popov and Nikolova1958). According to Mihailova *et al.* (1982), the species of this genus have one or two generation per year in Bulgaria. According to Popov and Nikolova (1958) and Mihailova *et al.* (1982), the beetles of the overwintering generation of *Phyllotreta sp*. emerge from the end of March to beginning of May, and the most damage occurs in May. When climatic conditions are appropriate, flea beetles can appear as early as February (Gruev and Tomov 1998). According to Mihailov *et al.* (1982), the emergence of the flea beetles in the spring in Bulgaria starts when the daily temperature exceeds 15°C. Prior to our first inspections of traps in 2007 (no temperature data for March, 2006 were available), daily temperature exceeded 15°C on 5, 18, 19 and 20th March; therefore, According to Grigorov (1972),Gruev and Tomov (1986) and (1998) adults of the new generation of *P. cruciferae, P. stirolata and P. nigripes* occur from July to the end of October–beginning of November, which corresponds again with our results. When the adult lays eggs in soil from the end of May onwards, the hatched larvae feed on either roots or leaf. Nevertheless, larval damage is not so severe as that of the adults (Evans 2003). They overwinter as adults in the leaf litter of shelterbelts or grassy areas and are rarely found in canola stubble. Beetles emerge when temperatures warm up to 57°F (14°C) in early spring. Depending on the temperature, it may take up to three weeks for the adults to leave their overwintering sites. Evans (2003) stated that the striped flea beetle adults usually emerge before the crucifer flea beetle. Warm, dry, and calm weather promotes flea beetle flight and feeding throughout the field, while simultaneously slowing canola growth. In contrast, cool, rainy, and windy conditions reduce flight activity, and flea beetles walk or hop leading to concentrations in the field margins. Females oviposit up to 25 eggs in the soil in June. The overwintered adults continue to remain active until late June and begin to die off in early July. Larvae hatch from the eggs in about 12 days and feed on the secondary roots of the plant. Larvae pass through three instars and complete their development in 25 to 34 days by forming small earthen puparium. The pupal stage lasts for about seven to nine days, usually in early to mid-July. The new generation adult emerges from the puparium beginning in late July until early September and feed on the epidermis of green foliage and pods of canola, mustard, and cruciferous weeds. The crop is usually mature enough that feeding damage is minimal.

Eggs

Eggs are yellow, oval, and about 0.38-0.46 mm long by 0.18-0.25 mm wide, and deposited singly or in groups of three or four adjacent to the host plants roots. In spring, one to four eggs, about 0.4mm long by 0.2 mm wide, oval and light yellow, are deposited near the bases of host plants.

Larvae

Larvae are small approximately 1/8 in. or 3 mm, whitish, slender, cylindrical worms. They have tiny legs and a brown head and anal plate. Mature larvae are approximately 3mm, white to very light brown with a copper-brown head and anal plate and are slender with small legs. Larvae feed on roots and root hairs and pupate in soil, emerging in late summer.

Pupae

Pupae are similar in size to the adult and white in color except for the black eyes and the free body appendages, which are visible later in the pupal development.

2.2.4 Nature of damage

Whiting and Wilson (2002) conducted an experiment on flea beetle and observed that adult flea beetle feed externally on plants, eating the surface of the leaves, stems and petals. Under heavy feeding the small round holes caused by an individual flea beetles feedings may coalesce into larger areas of damage. Some flea beetles are root feeders. In adverse weather conditions some flea beetles seek shelter in the soil. Some species, such as *Phyllotreta cruciferae* and *P. striolata*, prefer to leave their hide out only during jumping ability and this behavior of hiding in the soil. Flea beetles cause direct and indirect damage to cultivated plants. Direct damage is caused by both larvae and adults. Larvae injure roots or mine leaves while adults gnaw small pits or holes on the upper epidermis and parenchyma of the leaves. During the heavy infestations pitted areas merge and form larger holes on the leaves; later such leaves wilt and this can lead to delay in plant growth and yield reduction (Popov and Nikolova1958). Flea beetle larvae and adults also cause indirect damage by transmission of plant pathogens from infected cruciferous plants to healthy ones during feeding (Dillard *et al*. 1998, Glits 2000, Ryden 1989 and 1990, Saharan *et al.* 2005, Shelton and Hunter 1985 and Stobbs *et al.* 1998).

2.3 Tobacco caterpillar

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

2.3.1 Systematic position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Spodoptera*

Species: *S. litura* (Fabricius 1775)

2.3.2 Origin and distribution

The tobacco caterpillar is found throughout the tropical and subtropical parts of the world. It is wide spread in India (Atwal 1986). This pest has been reported from India, Pakistan, Srilanka, Mayanmar, Thailand, Malaysia, Cambodia, Laos, Vietnam, Sabah, Indonesia, the Philippines, Taiwan, Queensland, New South Wales, New Guinea, Papua, West Iran, Solomon Islands, Gilbert Islands, New Caledonia, Fiji, Samoa, Tonga, Society Islands, Gilbert Islands and Micronesia (Grist and Lever 1989).

2.3.3 Life cycle

Egg stage duration of the noctuid *S. litura* on sunflower in the laboratory was 3 days in May-June and 5.4 days in October. The duration of the larval stage averaged 15.09 days in June and 16.67 days in October. Larval survival varied from 72 to 92% in May October. The duration of the pupal stage averaged 7.49 days in September and 12.26 days in October. The adult life span averaged 4.1-6.2 days in males and 5.1-7.8 days in females. Studies at constant temperature of 20, 25 and 30°c showed the egg stage last for 5, 4 and 3 days, respectively (Kumar *et al.*1992).

2.3.4 Nature of damage

Tobacco caterpillar *Spodoptera litura* attack the tender leaves, larva cause the damage only. The female moth of tobacco caterpillar laid eggs on the lower surface of the leaves. After hatching of the eggs, the tiny caterpillar starts feeding on host plant. In the early stage of lettuce that was the the infestation was found to occur which caused a greater damage. In this stage caterpillars bored the new forming head and reached to the newly emerging little leaf and consumed it. Because of the excreta was left at the damaged site sometimes it causes rotting in the inner portion of lettuce. The nature of damage and extent of damage differed with age of the caterpillars. The young caterpillar along with mature caterpillar also cause greater damage if the infestation occurs at the head forming stage.

2.4 Aphid

2.4.1 Systematic position

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Homoptera

Family: Aphididae

Genus: *Lipaphis*

Species: *L. erysimi* (Kaltenbach 1843)

2.4.2 Life cycle

Lettuce crops are infested principally by four species of aphid: currant-lettuce aphid (*Nasonovia ribisnigri*), peach potato aphid (*Myzus persicae*), potato aphid (*Macrosiphum euphorbiae*) and lettuce-root aphid (*Pemphigus bursarius*). The first three species feed on the foliage, while the lettuce-root aphid feeds on the roots. The currant-lettuce aphid and lettuce-root aphid feed only on lettuce crops, while the other species have a wider host range.

2.4.3 Currant Lettuce Aphid

Currant lettuce aphid, *Nasonovia ribisnigri* is primarily a contamination pest of lettuce, chicory, endive and radicchio. CLA can also vector cucumber and lettuce mosaic virus although this has not been observed in infested crops. Currant lettuce aphids prefer to feed on new leaves. They can be found inside the wrapper leaves and hearts of iceberg lettuce varieties. In an open lettuce variety, they are found deep within the leaf rosette.

2.4.4 Description

Immature aphids are yellow-green and wingless. Adults can be winged or wingless and are 2.5 mm in length, greenish to yellow-green, with irregular narrow dark bands on the abdomen.

2.4.5 Distribution

Currant lettuce aphid is found in Europe, North America, South America (Argentina), New Zealand (2002) and all lettuce production areas of Australia (2004)

2.4.6 Hosts

Currant lettuce aphid has both wingless and winged forms. The primary host plants for this aphid species are gooseberry and red, black and white currants (*Ribes spp*.). To survive winter in cold temperate climates, the aphids lay eggs on gooseberries and currants. Chicory and endive (*Cichorium spp*.), nipplewort (*Lampsana spp*.), hawksbeard (*Crepis capillaris*), hawks weed (*Hieracium spp*.), speedwell (*Veronica spp*.), artichoke, tobacco and petunia are also secondary hosts.

2.5. Jute hairy caterpillar (*Spilosoma obliqua*)

2.5.1 Systemic classification of jute hairy caterpillar

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Eribidae

Subfamily: Arctiinae

Genus: *Spilosoma*

Species: *Spilosoma obliqua* (Walker 1855)

2.5.2 Life cycle

Information pertaining to different developmental stages of an insect species is a prerequisite for successful management of a pest (Nath and Singh 1996). Efforts have been made by many workers to study the biology of this pest on some leguminous crops (Chaudhary and Bhattarcharya1986, Singh and Gangrade 1974) the total larval period of six larval stages was 25 days, pupal period was 11 days, male and female longevity being 11 and 9 days respectively. The total life cycle took about 53 days and fecundity per female was about 951 eggs. Its biology was also studied by Nath and Singh (1996) reported that they laid eggs in parallel rows in cluster on the host leaf with incubation period ranged between 2-9 days but Singh and Gangrade (1974) reported the incubation period as 6-9 days. Life table statistics of *S. obliqua* were also studied by Varatharajan *et al*. (1998) on Sunflower and mentioned that egg hatched after 4 days and the total larval period was 28.8 days, pupal period was about 11 days and female laid about 530 eggs and adult female survived for 9 or 10 days under indoor rearing conditions.

Biology of *D. obliqua* was studied by Djou, (1938). He found that a female laid 342-1356 eggs in January, the incubation period was 6-11 days and the larvae development period was 29-38 days. The pupal period lasted for 5-6 days and the males lived for 12-24 days while 14-27 days for female. Kabir and Khan (1969) studied Biology of jute hairy caterpillar *Diacrisia obliqua*. They noted that the Arctiid had eight generations in a year. Each generation lasting from 5-8 weeks. The newly hatched larvae fed gregariously for 5 to 6 days, skeletonising the plants and afterwards dispersed and the plant defoliation was complete. Infestation began in the field in April or May and continued for about 3 months. The second and third generation occurred during the jute season are most injurious.

Bhuiyan and Sardar (1971) experimented the effects of rearing *D. obliqua* (WIk.) larvae under solitary and crowded conditions (5, 10 and 20 larvae/95.6 cm^3) in the laboratory at 28.9◦C and 85.2°/o RH. They observed that the duration of larval development averaged about 30, 22, 20 and 20 days respectively for increasing degrees of crowding.

Spilosoma obliqua (Walker) belongs to the family Arctiidae. Members of the Arctiids are mostly tropical with stout body and moderately broad, brightly coloured wings with spots or bands on them. They are nocturnal and capable of producing sound. Long hairs are present on larvae and feed on herbaceous plants. Larval hairs and silk are present on coccon(Nayar*et. al*. 1976).

Adsule and Kadak (1979) undertook the binomial studies of *D. obliqua* (Wlk.) on sunflower under laboratory conditions and observed that the female laid pale greenish and spherical eggs in clusters ranging the number 318 to 1830 eggs with an average of 774.62 eggs. The average incubation period was 5.64 days. There were six instars within 18- 28 days, the average being 20.86 days. Within silken cocoon, pupation took place and the pupal period lasted for 10 to 18 days. The average longevity of male and female moths was 6.71 and 8.82 days, respectively. They found 36.43 to 46.84 days with an average of 38.55 days in case of total life history. Patel (2015) observed that egg production of *D. obliqua* (Wlk.) was 400-1000 eggs, larval and pupal stages lasted for 6, 14-20, and 9 days, respectively.

2.5.3 Distribution of jute hairy caterpillar

S. obliqua has been reported to occur only in certain parts of South East Asia and it does not enjoy worldwide distribution. Besides India, it is known to occur in Bangladesh, Myanmar, Pakistan, Philippines and Sri Lanka (Singh and Sehgal 1992, Anonymous 1990). However, in the Indian context, this pest is practically reported from all over the country causing damage to a large number of cultivated as well as non-cultivated plant species (Gargav and Katiyar 1971,Dutt 1964,Mathur 1962, Fletcher 1922).

As this species being primarily polyphagous, its distribution and its density may differ from place to place, which may be in tune with climatic conditions of the place as well as the availability of natural enemies and pathogens in a given locality

2.6 Grasshopper

2.6.1 Systemic classification of grasshopper

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Orthoptera

Family: Acrididae

Subfamily: Oxyinae

Genus: *Oxya*

Species: *O. velox* (Fabricius 1787)

2.6.2 Characteristics of grasshopper

Grasshoppers have the typical insect body plan of head, thorax and abdomen. The head is held vertically at an angle to the body, with the mouth at the bottom. The head bears a large pair of compound eyes which give all-round vision, three simple eyes which can detect light and dark, and a pair of thread-like antennae that are sensitive to touch and smell. The downward-directed mouthparts are modified for chewing and there are two sensory palps in front of the jaws. The thorax and abdomen are segmented and have a rigid cuticle made up of overlapping plates composed of chitin. The three fused thoracic segments bear three pairs of legs and two pairs of wings. The forewings, known as tegmina, are narrow and leathery while the hind wings are large and membranous, the veins providing strength. The legs are terminated by claws for gripping. The hind leg is particularly powerful; the femur is robust and has several ridges where different surfaces join and the inner ridges bear stridulatory pegs in some species. The posterior edge of the tibia bears a double row of spines and there are a pair of articulated spurs near its lower end. The interior of the thorax houses the muscles that control the wings and legs. Ensifera, like this great green bush-cricket, *Tettigonia viridissima*, somewhat resemble grasshoppers but have over 20 segments in their antennae and different ovipositors.

The abdomen has eleven segments, the first of which is fused to the thorax and contains the tympanal organ and hearing system. Segments two to eight are ring-shaped and joined by flexible membranes. Segments nine to eleven are reduced in size; segment nine bears a pair of cerci and segments ten and eleven have the reproductive organs. Female grasshoppers are normally larger than males, with short ovipositors. The name of the suborder "Caelifera" comes from the Latin and means chisel-bearing, referring to the shape of the ovipositor. Those species that make easily heard noises usually do so by rubbing a row of pegs on the hind legs against the edges of the forewings (stridulation). These sounds are produced mainly by males to attract females, though in some species the females also stridulate. Grasshoppers may be confused with crickets, but they differ in many aspects; these include the number of segments in their antennae and the structure of the ovipositor, as well as the location of the tympanal organ and the methods by which sound is produced. Ensiferans have antennae that can be much longer than the body and have at least 20–24 segments, while caeliferans have fewer segments in their shorter, stouter antennae.

2.6.3 Life cycle

In most grasshopper species, conflicts between males over females rarely escalate beyond ritualistic displays. Some exceptions include the chameleon grasshopper (*Kosciuscola tristis*), where males may fight on top of ovipositing females; engaging in leg grappling, biting, kicking and mounting. The newly emerged female grasshopper has a pre-oviposition period of a week or two while she increases in weight and her eggs mature. After mating, the female of most species digs a hole with her ovipositor and lays a batch of eggs in a pod in the ground near food plants, generally in the summer. After laying the eggs, she covers the hole with soil and litter. Some, like the semi-aquatic *Cornops aquaticum*, deposit the pod directly into plant tissue. The eggs in the pod are glued together with a froth in some species. After a few weeks of development, the eggs of most species in temperate climates go into diapause, and pass the winter in this state. Diapause is broken by a sufficiently low ground temperature, with development resuming as soon as the ground warms above a certain threshold temperature. The embryos in a pod generally all hatch out within a few minutes of each other. They soon shed their membranes and their exoskeletons harden. These first instar nymphs can then jump away from predators. Grasshoppers undergo incomplete metamorphosis; they repeatedly moult, each instar becoming larger and more like an adult, with the wing-buds increasing in size at each stage. The number of instars varies between species but is often six. After the final moult, the wings are inflated and become fully functional. The migratory grasshopper, *Melanoplus sanguinipes*, spends about 25 to 30 days as a nymph, depending on sex and temperature, and lives for about 51 days as an adult.

2.7 Red pumpkin beetle

2.7.1 Systemic classification of red pumpkin beetle

Kingdom: Animalia

Phylum: Arthropoda

Class: Insrcta

Order: Coleoptera

Family: Chrysomelidae

Genus: *Raphidopalpa*

Species: *R. foveicollis* (Lucas 1849)

2.7.2 Origin and distribution of red pumpkin beetle

Hutson (1972) reported that the red pumpkin beetle occurs on various cucurbits in Ceylon. Pawlacos (1940) stated *Raphidopalpa foveicollis* (Lucas) as one of the most important pests of melon in Greece. Manson (1942) report-ed it to occur in Palestine. Azim (1996) indicated that the red pumpkin beetle, *Aulacophora foveicollis* (Lucas), is widely distributed throughout all zoogeographic regions of the world except the Neo-arctic and Neo-tropical region. Alam (1969) reviewed that the red pumpkin beetle, *Aulacophora foveicollis* (Lucas), is widely distributed throughout the Pakistan, India, Afghanistan, Ceylon, Burma, Indo-China, Iraq, Iran, Persia, Palestine, Greece, Turkey, Israel, South Europe, Algeria, Egypt, Cyprus and the Andaman Island. Butani and Jotwani (1984) reported that the RPB is widely distributed all over the South-East Asia as well as the Mediterranean region towards the west and Australia in the east. In India, it is found in almost all the states, though it is more abundant in the northern states (Butani and Jotwani1984). According to York (1992), this insect pest is found in the Mediterranean region, Africa and Asia.

2.7.3 Host preference of red pumpkin beetle

Alam*et al*. (1964) reported that bitter gourd, cucumber, snake gourd, sweet gourd, bottle gourd and many others plants are found to be seriously damaged by the red pumpkin beetle. He also indicated that melon, ribbed gourd, sponge gourd, snake gourd, cucumber, teasle gourd and kankri (*Cucumis utilissimus*) are also attacked by RPB in Bangladesh. Pradhan (1969) has reported that the RPB has a special preference for the leaves of cucurbit plants except those of the bitter gourd on which they have not been reported to feed to any appreciable extent. Azim (1966) reported that the insect feeds on tomato, maize and lucerne besides cucurbits in Greece. In addition, the pest was recorded to attack forest trees like *Dalbergia latifolia*, *Michela champaca* and *Tectona grandis* in India. He also reported that this insect was found to feed on rice plants in Indo-China. Butani and Jotwani (1984) reported that this beetle is a polyphagous pest and prefers cucurbit vegetables and melons. However, some leguminous crops are found as their main alternate hosts. According to Rahman and Annadurai (1985), the RPB is particularly severe pest of pumpkins, muskmelons and bottle gourds, but it appears to be able to feed on any available cucurbits. They also reported that when cucurbits are absent, it is found feeding on other plant families.

2.7.4 Damage caused by Red pumpkin beetle

Kabir *et al.* (1991) reported yield losses due to red pumpkin beetle infestation at seedlings stage varies in different fruits and vegetables and it was minimum in bitter gourd (19.19%) and maximum in sweet gourd (69.96%).Atwal (1993) found the red pumpkin beetle, *Aulacophora foveicollis* Lucas (Coleoptera: Chrysomelidae) was common and serious pest of a wide range of cucurbits, such as ash gourd (*Benincasa hispida*), pumpkin (*Cucurbita pepo* L.), tinda (*Citrullus vulgaris* var. fisulosus), ghiatori (*Luffa aegyptica*), cucumber and melon. Anonymous (1930) stated that in Bombay, research was performed on red pumpkin beetle and reported it to be the serious pest of the crop that is a more or less constant pest. It becomes sporadically serious on young tender shoots, leaves and flowers of various cucurbits. An investigation was done during 1955-57 and revealed that the adults of this beetle hibernate. Females beetle oviposit in May-August and egg stage last about 10, larval stage about 20 and pupal stage 16 days at 28°C [82.4°F.]. Egg laying capacity of female ranges from 100 to 800.

2.7.5 Seasonal abundance of Red Pumpkin Beetle

Khan *et al*. (2012) reported that the highest population of RPB was recorded in the month of May. Begum (2002) studied on sweet gourd, ash gourd, sponge gourd, snake gourd and cucumber against the fruit fly and red pumpkin beetle to identify the less and most preferred cucurbit host. Leaf canopy increases. Percent losses are obvious from the percent damage, which may reach up to 35-75% at seedling stage. Kamal *et al*. (2012) reported that effect of temperature on oviposition of red pumpkin beetle among different crops. The egg laying performance on three cucurbits at different controlled temperatures varied significantly. The maximum number of eggs was laid at 30ºC temperature followed by 25ºC and the lowest at 15ºC. According to Gupta and Verma (1992) and Dhillon *et al*. (2005), depending on the environmental conditions and susceptibility of the crop species, the extent of damage by red pumpkin beetle varies between 30 to 100%. To manage this serious pest it is necessary to study the effect of host and temperature on the feeding and oviposition of red pumpkin beetle. Borah (1999) studied the seasonality and varietal preference of red pumpkin beetle on sweet gourd and recorded highest number of beetles in rainy season.

2.8 Major classes of Biopesticide

In bio pesticides, there are certain of pesticide derived from natural materials as bacteria, certain minerals, animals, and plants. There are three types of major classes of biopesticides.

Biochemical pesticides

These are naturally occurring substances that control pests by nontoxic mechanisms. The conventional pesticides kill or disable the pest by contrast. Biochemical pesticides have some substance that interferes in mating, like sex pheromones, also different fragrance of plant extract attracts the pests to trap. Because it is sometimes difficult to determine whether a substance meets the criteria for classification as a biochemical pesticide, EPA has established a special committee to make such decisions.

Microbial pesticides

The microorganisms like virus, fungus, protozoan, or bacterium are the active ingredient in this type of pesticides. Each microorganism have specific active ingredient to control the specific pests, but microbial pesticides can control or kill many kinds of pests which damage the crop production. One fungus can control the weeds and other control or kill the insects-pests.

Plant-incorporated-protectants (PIPs)

These are pesticide substances produced by plants from genetic material which are inserted in plant. Scientists take the gene for BT pesticide protein and insert into plant's own genetic material. After inserting the gene of BT bacterium in the plant, the plant prepared the substance that can destroy or kill the pest. The plant's genetic material and protein, but not plant itself, regulated by EPA. An insect-toxic protein, Bb70p, was purified from *Beauveria bassiana* 70 using ammonium sulfate precipitation, ion exchange chromatography, and gel filtration. The protein caused high mortality by intra-hemocoel injection into *Galleria mellonella*. Thus, Bb70p appears to be an insect toxin protein, demonstrating novelty. Identification of this insect-toxic protein presents potential to enhance the virulence of *B. bassiana* through genetic manipulation.

CHAPTER III

MATERIALS AND METHODS

The present study was conducted to investigate the prevalence of insect pest of lettuce and biorational management of lettuce pests. This chapter deals with the information regarding materials and methods that were used in conducting the experiment. It consists of a short description of the experimental site, characteristics of soil, climate, materials of the investigation, layout and design of the experiment, land preparation, manuring and fertilizing, seed sowing, intercultural operations, harvesting, data collection procedure and statistical analysis etc. The materials and methods that were used in conducting the present experiment are described in this chapter.

3.1 Experimental period

The experiment was conducted during the period from 10 November, 2019 to 20 February, 2020.

3.2 Experimental Site

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

3.3 Climate of the experimental field

The climate of the experimental site was subtropical, characterized by heavy rainfall during the months from April to September (Kharif season) and scanty rainfall during the rest of the year (Rabi season). The total rainfall of the experimental site was 83.6 mm during the study period. The average monthly maximum and minimum temperature were 27.17ºC and 15.6ºC respectively during the experimental period. Rabi season is characterized by plenty of sunshine. The maximum and minimum temperature, humidity rainfall and soil temperature during the study period were collected from the Bangladesh Meteorological Department (Climate Division) and have been presented (Appendix II).

3.4 Soil of the experimental field

The soil of the experimental area belongs to the Madhupur Tract (UNDP 1988). The analytical data of the soil sample collected from the experimental area were determined in the SRDI, Soil Testing Laboratory, Khamarbari, Dhaka and presented in (Appendix III). The experimental site was a medium high land and P^H of the soil was 5.6. The morphological characters of soil of the experimental plots as indicated by FAO.

3.5 Planting Material

Seed of lettuce cultivar, *Lettuce ultima* was used in the experiment and sown on 10^{th} November, 2019. Seeds of lettuce variety-BARI I was collected from BARI, Gazipur. It was leafy and spreading type as well as heat tolerant in nature.

3.6 Experimental design and layout

The experiment was laid out following Randomized Complete Block Design (RCBD) with four replications. An area of 123 m^2 was divided into four equal blocks. Each block was divided into 6 plots where 6 treatments were allotted at random. Thus there were 24 unit plots altogether in the experimental field. The size of each plot was 1.6 m × 1.5 m. The distance between two blocks and two plots were 0.5 m and 0.5 m respectively (Figure 1).

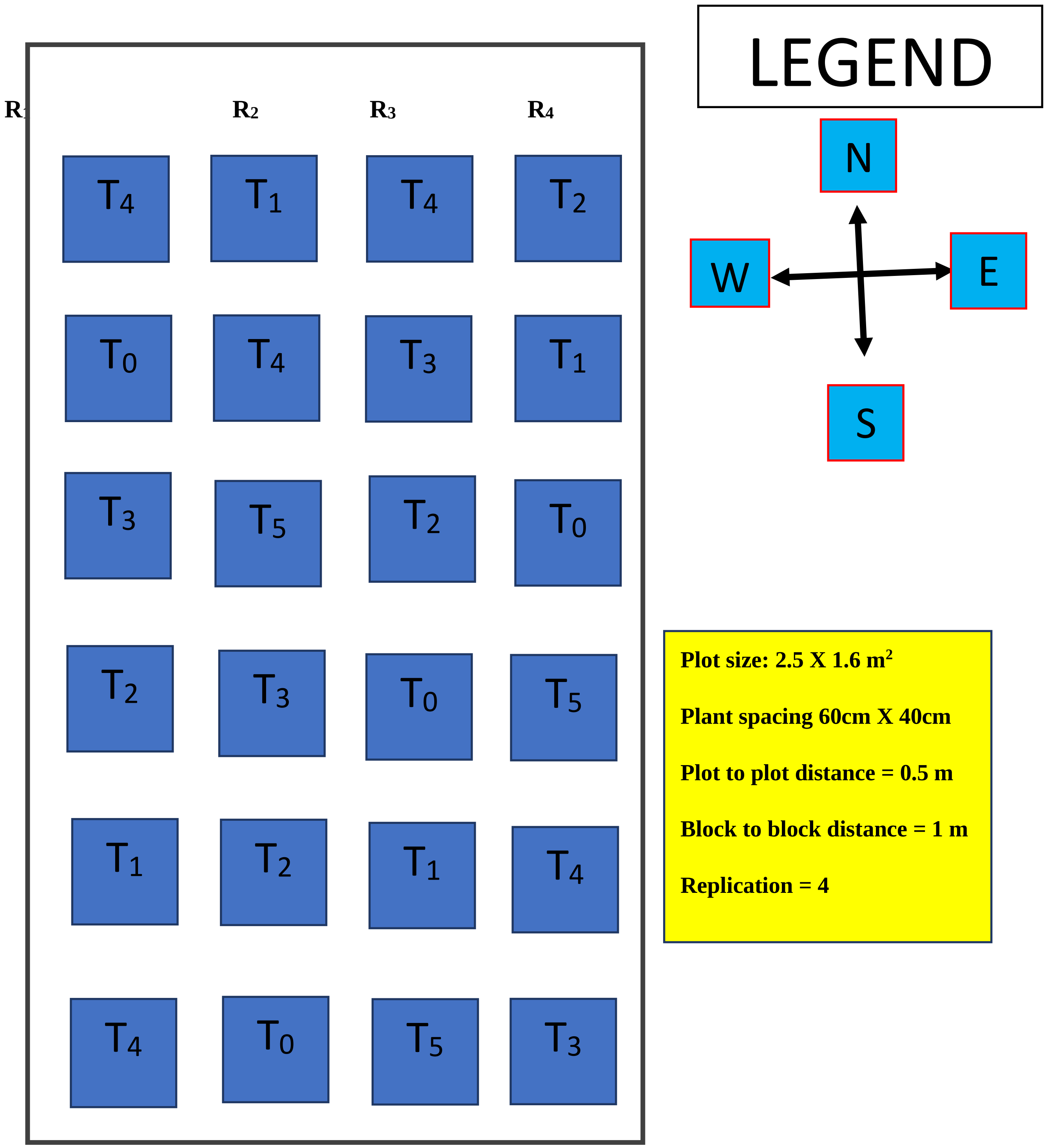
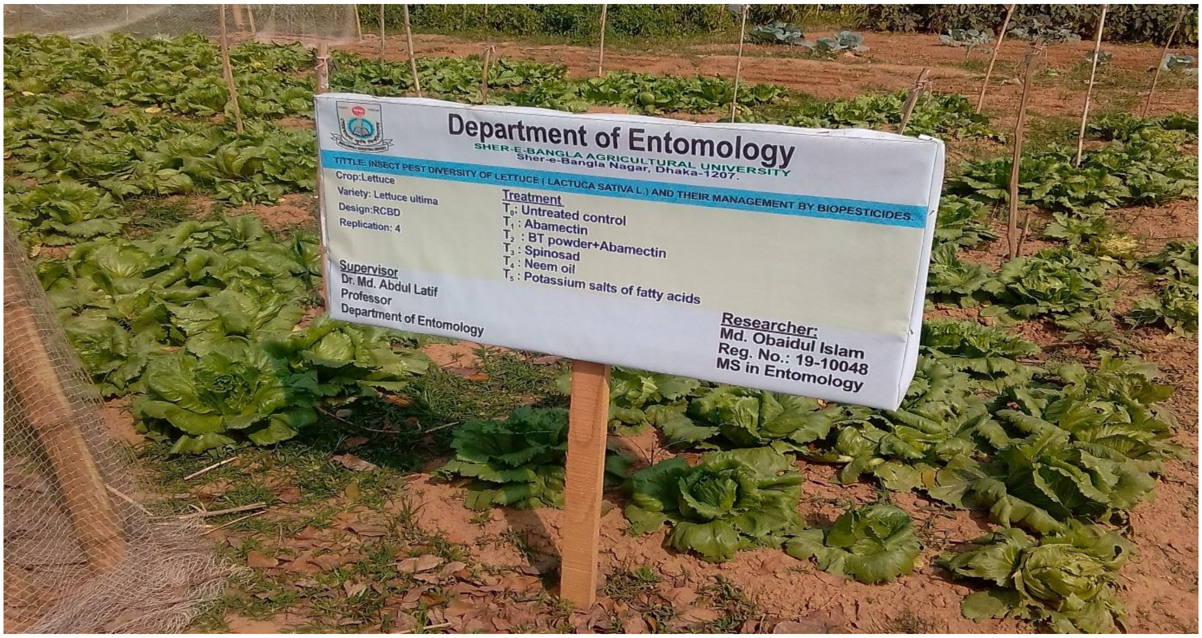


Figure 1. Layout of the experimental plot.



Plate(a)

Plate(b)

Plate 1 (a+b). Experimental field of lettuce during the study period.

3.7 Seed bed preparation, seed germination and seedlings raising

The selected seed bed was 3.0 m × 1.0 m in size. Seed beds were prepared with a mixture of sand, soil and compost. It was raised 15 cm from ground level. Germination of lettuce seed is a major problem in lettuce cultivation. Lettuce seed usually fails to germinate at temperature above 30ºC. Several workers have found that most lettuce seed may go into dormancy when subjected to high temperature and its exposure to chilling at 4-6ºC for 3-5 days result in breaking dormancy (Thomson and Kelly 1957). Lettuce seed were soaked in water for 48 hours and then seeds were mixed with soil and sown in seed bed. Lettuce seeds were sown on 10th November, 2019. Complete germination of seed took place for five days. Thirty days old seedlings were transplanted in the experimental field on 10th December, 2019 (Plate 2).

Plate 2. Lettuce seedlings in the seedbed.

3.8 Land preparation

The land which was selected to conduct the experiment ploughed 25 November 2019 with the help of a power tiller and then it was kept open to sun for 7 days prior to further ploughing. After that it was prepared by ploughing and cross ploughing followed by laddering. Deep ploughing was done to have good tilth which was necessary for getting better yield of the crop. The weeds and stubbles were removed after each laddering. Simultaneously the clods were broken and the soil was made into good tilth.

3.9 Application of manures and fertilizers

The sources of N, P_2O_5, K_2O were urea, TSP and MP, applied respectively. The entire amounts of TSP and MP were applied during the final land preparation. Urea was applied in three equal installments at 15, 30 and 45 days after seedling transplanting as per treatments. Well-rotten cowdung dung at 20 t/ha also applied during final land preparation. The following amount of manures and fertilizers were used which shown in tabular form as recommended by Rashid (1993).

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

Manures and fertilizers	**Amount applied**	
	Per hectare	**Per plot (5m$^{2)}$**
Cowdung	15 ton	7.25 kg
Poultry manure	7 ton	3.5 kg
Mustard oil cake	1 ton	450 g
Urea	250 kg	120 g
TSP	150 kg	70 g
MoP	120 kg	55 g

3.10 Transplanting of seedlings

Healthy and uniform sized, thirty days old seedlings were transplanted on 18th December 2019 in the afternoon and light irrigation was given around each seedling for their better establishment. The transplanted seedlings were protected from scorching sunlight by providing shed using banana leaf sheath. Dead seedlings were replaced by new seedlings from same stock.

3.11 Intercultural operation

When the seedlings were established in the beds, it was always kept under careful observation. Various intercultural operations like thinning, weeding were accomplished for better growth and development of lettuce seedlings.

3.11.1 Gap filing

Dead, injured and weak seedlings were replaced by new vigorous seedlings from the stock kept on the border line of the experiment field.

3.11.2 Weeding

Weeding was done three times in these plots wherever was necessary.

3.11.3 Irrigation

Light irrigation was given just after transplanting of the seedlings. A week after transplanting the requirement of irrigation was envisaged through visual estimation. The plots were irrigated in every alternative day with a hosepipe until the entire plot was properly wet Again, whenever the plants of a plot had shown the symptoms of wilting the plots were irrigated again.

3.11.4 Earthing up

Earthing up was done at 20 and 45 days after transplanting on both sides of rows by taking the soil from the space between the rows by a small spade.

3.12 Treatments used for management

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

Table 2. Treatments and application dose used in the experiment

Treatments	Trade name	Common name	Dose
T_1	Biomax 1.2EC	Abamectin	1.0 ml/L of water
T_2	Antario	*Bacillus thuringiensis* and abamectin	1.0 ml/L of water
T_3	Spinomax 45SC	Spinosad	0.5 ml/L of water
T_4	Bioneem plus 1EC	Azadiractin	1.0 ml/L of water
T_5	Fytomax	Potassium salts of fatty acid	1.0 ml/L of water
T_6	Untreated control	Water	-

Plate 3. (A) Abamectin1.2 EC, **(B)** *Bacillus thuringiensis* and abamectin, **(C)** Spinosad45SC, **(D)** Azadirachtin1 EC, **(E)** Potassium salt of fatty acid.

3.14 Sampling

However, sweep net sampling, which is usually applied to assess population size of the harmful stage of many agricultural pests is not suitable for flea beetle monitoring because the beetles can move into the field quickly, which is connected with the presence of meta femoral spring (Furth, 1988). For sampling of flea beetle sweeping net was used due to lack of other sampling method.

3.15 Preservation of insects

The available species of flea beetles were collected from the research field. In the laboratory, specimens were pinned, dried, labeled and kept in collection boxes. The specimens were identified to species under microscope using the taxonomic keys of Maulik (1936) and Aston (2009).

3.16 Species identification

Species identification was according to mainly external marks such as color and patterns of the elytrae, the shape of the yellow patterns, punctation of the head and the forehead, presence or absence of metallic shade on the back of the prothorax and the elytrae, the specific color of the elytrae, the shape of the prothorax, the punctation of the elytrae, the color of the segments of the antenna, the tibia and the tarsus (Gruev and Tomov 1986, Kaszab 1962).

3.17 Data collection

Data were recorded on the following parameters from the sample plants during the course of experiment. Six plants were sampled randomly from each unit plot for the collection of data.

3.18 Determination of leaf infestation by number and infestation reduction over control

All the healthy and infested leaf were counted from 6 plants from each plot and examined carefully. The healthy and infested leaves were counted at for different insect pests and converted into per plant and then the percent leaf infestation was calculated using the following formula:

Leaf infestation (%) = (Number of infested leaves/ Total number of leaves) × 100 ……….. (i)

3.19 Assessment of treatment effect

The uninfested and infested leaves and plants of lettuce caused by the flea beetles were counted. The observations were recorded at the first observation of no. of damage leaves and plants and were continued up to harvesting stage of the lettuce at 7 days of interval. The data on the yield was also recorded. The level of leaf and plant infestations per plant and plot respectively was then calculated using the following formula:

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

3.20 Statistical analysis

The collected data on various parameters were statistically analyzed using MSTAT-C package programmers. The mean for all the treatments were calculated and analyzed and analyses of variance of all the characters were performed by F-variance test. The significance of differences between the pairs of treatment means was calculated by the least significant difference (LSD) test at 5% level of probability (Gomez and Gomez 1984).

Plate 4. Lettuce plant infested by jute hairy caterpillar.

Plate 5. Lettuce plant infested by flea beetle.

Plate 6. Lettuce plant infested by tobacco caterpillar.

Plate 7. Healthy Lettuce plant.

Plate 8. Larva of tobacco caterpillar.

Plate 9. Pupa of tobacco caterpillar.

Plate 10. Pupa and adult of tobacco caterpillar.

Plate 11. Applying Treatments

CHAPTER IV

RESULT AND DISSCUSSION

The experiment was conducted to investigate the insect pests of lettuce and management of major ones using biorationals. Data were recorded on pest incidence and leaf infestation due to different insect pests. The results had been presented and discussed under the following sub-headings:

4.1 Incidence of insect pests

Flea beetle (*Monolepta signata* Olivier), tobacco caterpillar (*Spdoptera litura* Fabricius), aphid (*Lipaphis erysimi* Kaltenbach), jute hairy caterpillar (*Spilosoma obliqua* Walker), grasshopper (*Oxya velox* Fabricius) and red pumpkin beetle (*Raphidopalpa foveicollis* Lucas) were observed in the field (Table 3).

Table 3. List of insect pests observed in lettuce field

No.	Common Name	Scientific name	Order	Family	Starting infestation	Infestation period
1.	Flea beetle	*Monolepta signata*	Coleoptera	Chrysomelidae	December	December-February
2.	Tobacco caterpillar	*Spodoptera litura*	Lepidoptera	Noctuidae	January	January-February
3.	Aphid	*Macrosiphum sp.*	Hemiptera	Aphididae	January	January-February
4.	Jute hairy caterpillar	*Spilosoma obliqua*	Lepidoptera	Noctuidae	November	November-February
5.	Grasshopper	*Oxya velox*	Orthoptera	Acrididae	November	November-February
6.	Red pumpkin beetle	*Raphidopalpa foveicollis*	Coleoptera	Chrysomelidae	February	February

4.2 Effect of biorationals on infestation of insect pests of lettuce

4.2.1 Effect of biorationals on Flea beetle infestation

Number of healthy leaves, infested leaves and percent leaf infestation of lettuce by flea beetle showed statistically significant differences in different biorationals based management practices (Table 4). The highest number of healthy leaves/plant (26.27) was observed in T_3 (Spinosad 45SC @ 0.5 ml/L of water at 7 days interval) treatment which was closely followed (24.30 and 22.98) to T_1 (Abamectin1.2EC @ 1.0 ml/L of water at 7 days interval) and T_5 (Spraying of Potassium salt of fatty acid @ 1.0 ml/L of water at 7 days interval), respectively, whereas the lowest number (21.24) was recorded in T_6 (untreated control) treatment which was statistically similar (21.52) to T_2 (Spraying of *Bacillus thuringiensis* and abamectin @ 1.0 ml/L of water at 7 days interval) and closely followed T_4 (Spraying of Azadirachtin1EC @ 1.0 ml/L of water at 7 days interval).

Data in Table 4 also expressed that the highest percent of leaf infestation (26.93%) was recorded in T_6 (untreated control) which was significantly different from all other treatments. But in the treated plots, the highest percent of leaf infestation was found in T_5 (23.26%) which was closely followed T_1 (21.07%) and T_2 (19.75%) which was statistically similar with T_4. On the other hand, the lowest leaf infestation intensity was observed in T_3 (10.70%) which was significantly different from all other treatments. The results obtained from other treatments showed intermediate level of leaf infestation intensity. In case of percent reduction of leaf infestation over control, the highest reduction over control on leaf infestation intensity was achieved (60.27%) by T_3 treatment whereas the lowest result (13.63%) was obtained in T_5 (Table 4).

From the above findings it is clear that among the different treatments, T_3 performed best in reducing the infestation intensity of leaf (60.27%) of lettuce by flea beetle than the other treatments; whereas, T_5 showed the least performance in reducing the infestation intensity of leaf (13.63%) of lettuce by flea beetle. As a result, the order of trend of efficacy among the different treatments including one untreated control in terms of reducing the infestation intensity of leaf of lettuce was $T_3 > T_4 > T_2 > T_1 > T_5 > T_6$.

Table 4. Effect of biorationals on leaf infestation of lettuce by flea beetle in Rabi season

Treatments	Number of healthy leaves $plant^{-1}$	Number of infested leaves $plant^{-1}$	Percent leaf infestation	Percent decrease of leaf infestation over control
T_1	24.30 b	6.26 c	21.07 c	21.76
T_2	21.52 de	5.29 d	19.75 d	26.66
T_3	26.27 a	3.11 e	10.70 e	60.27
T_4	22.21 d	5.18 d	18.87 d	29.93
T_5	22.98 c	6.71 b	23.26 b	13.63
T_6	21.24 e	8.35 a	26.93 a	--
LSD (0.05%)	**0.73**	**0.41**	**0.95**	**--**
Level of significance	**0.05**	**0.05**	**0.05**	**--**
CV (%)	**2.18**	**4.82**	**3.24**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.2.2 Effect of biorationals on Tobacco caterpillar infestation

Number of healthy leaves, infested leaves and percent leaf infestation of lettuce by tobacco caterpillar showed statistically significant differences in various biorational management practices (Table 5). The highest number of healthy leaves/plant (24.38) was observed in T_3 (Spinosad 45SC @ 0.5 ml/L of water at 7 days interval) treatment which was closely followed 22.43 and 22.33) in T_2 (*Bacillus thuringiensis* and abamectin @ 1.0 ml/L of water at 7 days interval) and T_1 (Abamectin1.2EC @ 1.0 ml/L of water at 7 days interval), respectively. In contrast, the lowest number of healthy leaves of lettuce (19.19 leaves plant^{-1}) was recorded in T_6 (untreated control) treatment which was statistically similar (19.27) to T_5 (Potassium salt of fatty acid @ 1.0 ml/L of water at 7 days interval) and closely followed T_4 (Azadirachtin 1.0EC @ 1.0 ml/L of water at 7 days interval).

The highest percent leaf infestation intensity (18.81%) was recorded in T_6 (untreated control) which was significantly different from all other treatments. But in the treated plots, the highest percent of leaf infestation was found in T_5 (14.45%) which was closely followed T_4 (13.07%) and T_2 (10.46%). On the other hand, the lowest percent leaf infestation intensity was observed in T_3 (4.67%) which was significantly different from all other treatments followed by T_1 (9.10%). Results also revealed that among the different treatments, T_3 performed best in reducing the infestation intensity of leaf (75.17%) of lettuce by tobacco caterpillar than the other treatments (Table 5) whereas, T_5 showed the least performance in reducing the infestation intensity of leaf (23.18%) of lettuce by tobacco caterpillar (Table 5). In case of percent reduction of leaf infestation of tobacco caterpillar over control, the highest percent reduction over control on leaf infestation was achieved (75.17%) by T_3 treatment as against the lowest was in T_5 (23.18%). Thus, T_3 (Spinosad) treatment performed the best in reducing tobacco caterpillar infestation in lettuce. The order of efficacy among the different treatments including one untreated control in terms of reducing the infestation intensity of tobacco caterpillar was $T_3 > T_1 > T_2 > T_4 > T_5 > T_6$.

Table 5. Effect of biorationals on leaf infestation of lettuce by tobacco caterpillar in rabi season

Treatments	Number of healthy leaves plant^{-1}	Number of infested leaves plant^{-1}	Percent leaf infestation	Percent decrease of leaf infestation over control
T_1	22.33 b	2.23 c	9.10e	51.62
T_2	22.43 b	2.24 c	10.46d	44.39
T_3	24.38 a	1.19 d	4.67f	75.17
T_4	21.26 c	3.19 b	13.07c	30.51
T_5	19.27 d	3.25 b	14.45b	23.18
T_6	19.19 d	5.20 a	18.81a	--
LSD (0.05%)	**0.34**	**0.16**	**0.54**	**--**
Level of significance	**0.05**	**0.05**	**0.05**	**--**
CV (%)	**1.09**	**3.93**	**3.18**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.2.3 Effect of biorationals on Aphid infestation

Number of healthy leaves, infested leaves and percent leaf infestation of lettuce by aphid showed statistically significant differences due to different management practices (Table 6). The highest number of healthy leaves/plant (24.46) was observed in T_3 (Spinosad 45SC @ 0.5 ml/L of water at 7 days interval) treatment which was closely followed by (22.22) T_1 (Abamectin1.2EC @ 1.0 ml/L of water at 7 days interval) treatment, whereas the lowest number (20.15) was recorded in T_6 (untreated control) treatment which was closely followed by (20.55) T_4 (Azadirachtin1EC @ 1.0 ml/L of water at 7 days interval). It was also noted that the highest percent leaf infestation (18.22%) was recorded in T_6 (untreated control) which was significantly different from all other treatments. But among the treated plots, the highest percent leaf infestation was found in T_5 (12.51%) which was followed by T_4 (10.57%) and T_2 (7.86%). On the other hand, the lowest leaf infestation intensity was observed in T_3 (4.76%) which was closely followed T_1 (6.81) having significant difference between them.

In terms of percent of reduction of aphid infestation over control, T_3 treatment (Spinsad 45SC) showed best result by reducing 73.87% leaf infestation by aphid over untreated control as against the lowest in T_5 which reduced only 31.34% infestation of aphid (Table 6). Thus, the lowest number infested leaf, minimum percent of leaf infestation and highest percent reduction of aphid infestation was observed in T_3 treatment (Spinosad 45SC) among the five biorationals. The order of efficacy among the different treatments including one untreated control was

$T_3 > T_1 > T_2 > T_4 > T_5 > T_6$.

Table 6. Effect of biorationals on leaf infestation of lettuce by aphid in rabi season

Treatments	Number of healthy leaves plant^{-1}	Number of infested leaves plant^{-1}	Percent leaf infestation	Percent decrease of leaf infestation over control
T_1	22.22 b	1.62 d	6.81 e	62.62
T_2	21.30 c	1.81 d	7.86 d	56.86
T_3	24.46 a	1.22 e	4.76 f	73.87
T_4	20.51 d	2.43 c	10.57 c	41.99
T_5	21.15 c	2.88 b	12.51 b	31.34
T_6	20.15 e	4.71 a	18.22 a	--
LSD (0.05%)	**0.20**	**0.26**		**--**
Level of significance	**0.05**	**0.05**		**--**
CV (%)	**0.66**	**7.31**		**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.2.4 Effect of biorationals Jute hairy caterpillar infestation

Number of healthy leaves, infested leaves and percent leaf infestation of lettuce by jute hairy caterpillar showed statistically significant differences due to different management practices (Table 7). The highest number of healthy leaves/plant (23.48) was observed in T_3 (Spinosad 45SC @ 0.5 ml/L of water at 7 days interval) treatment which was closely followed by 21.65, 21.40 and 21.09 in T_1 (Abamectin1.2EC @ 1.0 ml/L of water at 7 days interval), T_5 (Potassium salt of fatty acid @ 1.0 ml/L of water at 7 days interval) and T_4 (Azadirachtin 1EC @ 1 ml/L of water at 7 days interval), respectively. In contrast, the lowest number of healthy leaves (19.42/plant) was recorded in T_6 (untreated control) treatment which was significantly lower than other treatments. Result also demonstrated that the lowest number of jute hairy caterpillar infested leaves (1.25) was recorded from Spinosad 45SC treated plots which was significantly lower than other treatments. In contrast, the highest number of jute hairy caterpillar infested leaves (11.85) was recorded from untreated control plots (Table 7).

It was also observed that the highest percent leaf infestation intensity (37.67%) was recorded in T_6 which was significantly different from all other treatments. But in the treated plots, the highest leaf infestation intensity was found in T_5 (18.33%) which was statistically similar with T_4 (17.14%) and closely followed by T_2 (14.81%). On the other hand, the lowest leaf infestation intensity was observed in T_3 (10.70%) which was closely followed T_1 (10.44). In case of percent reduction of leaf infestation over control, the best result was achieved (86.54%) by T_3 treatment as against the lowest in T_5 (51.34%) (Table 7). The order of efficacy among the different treatments including one untreated control in terms of leaf infestation of lettuce by jute hairy caterpillar was $T_3 > T_1 > T_2 > T_4 > T_5 > T_6$.

Table 7. Effect of biorationals on leaf infestation of lettuce by Jute hairy caterpillar in rabi season

Treatments	Number of healthy leaves $plant^{-1}$	Number of infested leaves $plant^{-1}$	Percent leaf infestation	Percent decrease of leaf infestation over control
T_1	21.65 b	2.53 d	10.44 d	72.29
T_2	19.66 c	3.38 c	14.81 c	60.68
T_3	23.48 a	1.25 e	5.07 e	86.54
T_4	21.09b	4.36 b	17.14 b	54.50
T_5	21.40 b	4.80 b	18.33 b	51.34
T_6	19.42 c	11.85 a	37.67 a	--
LSD (0.05%)	**1.25**	**0.53**	**1.95**	**--**
Level of significance	**0.05**	**0.05**	**0.05**	**--**
CV (%)	**4.12**	**7.84**	**7.85**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.2.5 Effect of biorationals on Grasshopper infestation

Number of healthy leaves, infested leaves and percent leaf infestation of lettuce by grasshopper showed statistically significant differences due to different management practices (Table 8). The highest number of healthy leaves/plant (23.40) was observed in T_3 (Spinosad45SC @ 0.5 ml/L of water at 7 days interval) treatment which was closely followed (22.27) by T_1 (Spraying of Abamectin 1.2EC @ 1 ml/L of water at 7 days interval) treatment, whereas the lowest number (19.35) was recorded in T_6 (untreated control) treatment which was statistically similar (19.44 and 19.47) by T_5 (Spraying of Potassium salt of fatty acid @ 1 ml/L of water at 7 days interval) and T_2 (Spraying of *Bacillus thuringiensis* and abamectin@ 1 ml/L of water at 7 days interval)

The highest leaf infestation intensity (24.70%) was recorded in T_6 (untreated control) which was significantly different from all other treatments. But in the treated plots, the highest leaf infestation intensity was found in T_5 (15.15%) which was closely followed T_4 (13.67%) and closely followed T_2 (12.36%). On the other hand, the lowest leaf infestation intensity was observed in T_3 (5.03%) which was closely followed T_1 (9.00). The results obtained from other treatments showed intermediate level of leaf infestation intensity. So, it can be observed that the leaf infestation intensity among the treatments from highest to the lowest was shown as

$T_6 > T_5 > T_4 > T_2 > T_1 > T_3$.

In case of % reduction over control, the highest reduction over control on leaf infestation intensity was achieved (79.64%) by T_3 treatment where the lowest was found in T_5 (38.66%) (Table 8).From the above mentioned findings it was revealed that among the different treatments, T_3 performed best in reducing the infestation intensity of leaf (79.64%) of lettuce by grasshopper than the other treatments; whereas, T_5 showed the least performance in reducing the infestation intensity of leaf (38.66%) of lettuce by grasshopper. As a result, the order of trend of efficacy among the different treatments including one untreated control in terms of reducing the infestation intensity of leaf of lettuce was

$T_3 > T_1 > T_2 > T_4 > T_5 > T_6$.

Table 8. Effect of biorationals on leaf infestation of lettuce by grasshopper in rabi season

Treatments	Number of healthy leaves plant^{-1}	Number of infested leaves plant^{-1}	Percent leaf infestation	Percent decrease of leaf infestation over control
T_1	22.27 b	2.20 e	9.00 e	63.56
T_2	19.47 d	2.75 d	12.36 d	49.96
T_3	23.40 a	1.24 f	5.03 f	79.64
T_4	20.23 c	3.20 c	13.67 c	44.66
T_5	19.44 d	3.46 b	15.15 b	38.66
T_6	19.35 d	6.47 a	24.70 a	--
LSD (0.05%)	**0.26**	**0.24**	**0.84**	**--**
Level of significance	**0.05**	**0.05**	**0.05**	**--**
CV (%)	**0.88**	**5.36**	**4.34**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.2.6 Effect of biorationals red pumpkin beetle infestation

Number of healthy leaves, infested leaves and percent leaf infestation of lettuce by red pumpkin beetle showed statistically significant differences due to different management practices (Table 9). The highest number of healthy leaves/plant (26.37) was observed in T_3 (Spinosad 45SC @ 0.5 ml/L of water at 7 days interval) treatment which was closely followed (24.21 and 22.88) to T_1 (Abamectin1.2EC @ 1 ml/L of water at 7 days interval) and T_5 (Potassium salt of fatty acid @ 1 ml/L of water at 7 days interval), respectively, whereas the lowest number (21.28) was recorded in T_6 (untreated control) treatment which was statistically similar (21.45) to T_2 (*Bacillus thuringiensis* and abamectin@ 1 ml/L of water at 7 days interval) and closely followed T_4 (Spraying of Azadirachtin 1EC @ 1 ml/L of water at 7 days interval).

The highest leaf infestation intensity (26.93%) was recorded in T_6 which was significantly different from all other treatments. But in the treated plots, the highest leaf infestation intensity was found in T_5 (23.26%) which was closely followed T_1 (21.07%) and T_2 (19.75%) which was statistically similar with T_4. On the other hand, the lowest leaf infestation intensity was observed in T_3 (10.70%) which was significantly different from all other treatments. The results obtained from other treatments showed intermediate level of leaf infestation intensity. So, it can be observed that the leaf infestation intensity among the treatments from highest to the lowest was shown as

$T_6 > T_5 > T_1 > T_2 > T_4 > T_3$. In case of % reduction over control, the highest reduction over control on leaf infestation intensity was achieved (60.32%) by T_3 treatment where the lowest was found in T_5 (13.61%) (Table 9).

From the above mentioned finding it was revealed that among the different treatments, T_3 performed best in reducing the infestation intensity of leaf (60.32 %) of lettuce by red pumpkin beetle than the other treatments; whereas, T_5 showed the least performance in reducing the infestation intensity of leaf (13.63%) of lettuce by red pumpkin beetle. As a result, the order of trend of efficacy among the different treatments including one untreated control in terms of reducing the infestation intensity of leaf of lettuce was $T_3 > T_4 > T_2 > T_1 > T_5 > T_6$.

Table 09. Effect of biorationals on leaf infestation of lettuce by red pumpkin beetle in rabi season

Treatments	Number of healthy leaves plant^{-1}	Number of infested leaves plant^{-1}	Percent leaf infestation	Percent decrease of leaf infestation over control
T_1	24.21 b	4.26 c	21.07 c	21.71
T_2	21.45 de	3.29 d	19.75 d	26.70
T_3	26.37 a	1.11 e	8.74 e	65.32
T_4	22.19 d	3.18 d	18.87 d	29.84
T_5	22.88 c	4.71 b	23.26 b	13.61
T_6	21.28 e	6.35 a	26.73 a	--
LSD (0.05%)	**0.73**	**0.41**	**0.95**	**--**
Level of significance	**0.05**	**0.05**	**0.05**	**--**
CV (%)	**2.18**	**4.82**	**3.24**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.3 Effect of biorationals on weight and yield of lettuce

4.3.1 Single plant weight (kg) during harvesting

Significant variations were observed among the different treatments used for the management practices in terms of single plant weight. The highest single plant weight (0.91 kg) was recorded in T_3 which was statistically different from all other treatments and followed by T_1 (630g) and T_2 (0.53 kg). On the other hand, the lowest single plant weight (0.24 kg) was found in T_6 which was significantly different from all other treatments. But in the treated plots, the lowest single plant weight (0.42 kg) was found in T_4 which was statistically similar with T_5 (0.43 kg). The gradually decreasing rank was observed in case of single plant weight as $T_3 > T_1 > T_2 > T_4 > T_5 > T_6$ (Table 10).

In terms of % increase over control, the highest increase over control on single plant weight was observed with the treatment of T_3 (73.63%) where the lowest was achieved from T_4 (42.86%) which was very close to T_5 (44.19%) (Table 10). As a result, the order of rank of efficacy among the different treatments including one untreated control in terms of in percent increasing diameter of plant at harvesting was $T_3 > T_1 > T_2 > T_4 > T_5 > T_6$ (Table 10).

4.3.2 Total yield (ton ha^{-1})

Significant variations were observed among the different treatments used for the management practices in terms of total yield (ton ha^{-1}). The highest total yield (16.43 ton ha^{-1}) was recorded in T_3 which was statistically different from all other treatments followed by T_1 (14.12 ton ha^{-1}) which was statistically similar with T_5 (14.13 ton ha^{-1}). The lowest total yield (7.08 ton ha^{-1}) was found in T_6 which was significantly different from all other treatments. But in the treated plots, the lowest total yield (13.19 ton ha^{-1}) was found in T_4 which was closely followed by T_2 (13.50 ton ha^{-1}). The gradually decreased trend was observed in case of total yield as $T_3 > T_1 > T_2 > T_4 > T_5 > T_6$ (Table 10). In terms of % increase over control, the highest increase over control on total yield (ton ha^{-1}) was observed with the treatment of T_3 (57.43%) which followed by T_5 (49.89%) and T_1 (49.86%) whereas the lowest was achieved from T_4 (46.32%) which was very close to T_2 (47.56%) (Table 10). As a result, the order of rank of efficacy among the different treatments including one untreated control in terms of in percent increase of total yield (ton ha^{-1}) at harvesting was $T_3 > T_1 > T_2 > T_4 > T_5 > T_6$.

Table 10. Individual plant wt. and yield of lettuce in different treatments during harvesting in rabi season

Treatments	Single plant weight (kg)	Percent increase over control	Total yield (ton ha^{-1})	Percent increase over control
T_1	0.63 b	61.90	14.12 b	49.86
T_2	0.53 c	54.72	13.50 c	47.56
T_3	0.91 a	73.63	16.43 a	57.43
T_4	0.42 d	42.86	13.19 d	46.32
T_5	0.43 d	44.19	14.13 b	49.89
T_6	0.24 e	--	7.08 e	--
LSD 0.05%	**0.08**		**023**	**--**
Level of Significance	**0.05**		**0.05**	**--**
CV%	**3.27**		**1.21**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.3.4 Infested plant weight (kg) plant-1 during harvesting

Significant variations were observed among the different treatments used for the management practices in terms of infested plant weight/plant due to attack of insect pests during harvesting (Table 11). The highest infested plant weight plant^{-1} (0.49 kg) was recorded in T_3 which was statistically similar with all other treatments followed by the untreated control T_6 (0.22 kg). But in the treated plots, the lowest infested plant weight plot^{-1} (0.23 kg) was found in T_5 which was closely followed by T_4 (0.30 kg). The gradually decreased trend was observed in case of healthy plant weight plot^{-1} as T_3> T_1> T_2> T_4> T_5> T_6. In terms of (%) increase over control, the highest increase over control on infested plant weight plant-^{1} was observed with the treatment of T_3 (55.10%) followed by T_1 (40.54%) and T_2 (37.14%). Whereas the lowest was achieved from T_5 (4.34%) which was close to T_4 (26.67%) (Table 11). As a result, the order of rank of efficacy among the different treatments including one untreated control in terms of in percent increase of total yield (ton ha^{-1}) at harvesting was T_3> T_1> T_2> T_4> T_5> T_6.

4.3.5 Healthy plant weight (kg) plant-1 during harvesting

Significant variations were observed among the different treatments used for the management practices in terms of healthy plant weight/plant due to attack of insect pests during harvesting (Table 11). The highest healthy plant weight plant^{-1} (0.76 kg) was recorded in T_3 which was followed by T_1 (0.59 kg). On the other hand, the lowest healthy plant weight plant^{-1} (0.29 kg) was found in T_6 which was significantly different from all other treatments. But in the treated plots, the lowest healthy plant weight/plant (0.42 kg) was found in T_4 which was statistically similar with T_5 (0.44 kg). The results obtained from T_2 (0.57 kg) gave intermediate results of healthy plant weight plant^{-1}. The gradually decreased trend was observed in case of healthy plant weight plot^{-1} as T_3> T_1> T_2> T_4> T_5> T_6. In terms of (%) increase over contro0l, the highest increase over control on healthy plant weight plant^{-1} was observed with the treatment of T_3 (61.84%) followed by T_1 (50.85%) and T_2 (49.12%). Whereas the lowest was achieved from T_4 (30.95%) which was very close to T_5 (34.09%) (Table 11). As a result, the order of rank of efficacy among the different treatments including one untreated control in terms of in percent increase of total yield (ton ha^{-1}) at harvesting was T_3> T_1> T_2> T_4> T_5> T_6 (Table 11).

Table 11. Infested and healthy plant weight of lettuce in different treatments during harvesting

Treatments	Infested plant weight (kg)	Percent decrease over control	Healthy plant weight (kg)	Percent increase over control
T_1	0.37 ab	40.54	0.59 b	50.85
T_2	0.35 ab	37.14	0.57 bc	49.12
T_3	0.49 a	55.10	0.76 a	61.84
T_4	0.30 b	26.67	0.42 cd	30.95
T_5	0.23 b	4.35	0.44 cd	34.09
T_6	0.22 b	--	0.29 d	--
LSD 0.05%	**0.14**	**--**	**0.14**	**--**
Level of Significance	**0.05**	**--**	**0.05**	**--**
CV%	**4.23**	**--**	**2.92**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

4.4 Percent (%) infestation of leaves by number during harvesting

Significant variations were observed among the different treatments used for the management practices in terms of number of (%) infestation of leaves by number due to attack of insect pests during harvesting period (Table 12).

The highest (%) infestation of leaves by number (21.50) was recorded in T_6 which was significantly different from all other treatments. But in the treated plots, the highest (%) infestation of leaves by number was found in T_5 (14.80) which was statistically similar with T_4 (14.05%). On the other hand, the lowest (%) infestation of leaves by number was observed in T_3 (8.64) which was followed by T_1 (11.22) significantly similar with T_2 (12.01).

The results obtained from other treatments gave the intermediate level of (%) infestation of leaves by number. So, it can be stated that the (%) infestation of leaves by number among the treatments from highest to the lowest was shown as $T_6 > T_5 > T_4 > T_2 > T_1 > T_3$.

In case of percent reduction over control, the highest reduction over control on percent infestation of leaves by number was found by T_3 (59.40%) where the lowest was found in T_5 (30.98%) which was very close to T_4 (34.58%) (Table 12). From the above mentioned findings it was revealed that among the different treatments, T_3 performed the best results in reducing the infestation intensity of leaves by insect pests (59.40%) at harvesting than the other treatments; whereas, T_5 showed the least performance results in reducing the infestation intensity of leaves by number by insect pests (30.98%) at harvesting over control. As a result, the order of trend of efficacy among the different treatments including one untreated control in terms of reducing the infestation intensity of leaves by number by insect pests at harvesting was

$T_3 > T_1 > T_2 > T_4 > T_5 > T_6$.

Table 12. Infestation intensity of lettuce by different insect pests in different treatments during harvesting

Treatments	Percent leaf infestation at harvest	Percent reduction of leaf infestation over control
T_1	11.22 c	47.79
T_2	12.01 c	43.81
T_3	8.64 d	59.40
T_4	14.05 b	34.58
T_5	14.80 b	30.98
T_6	21.50 a	
$LSD_{(0.05)}$	**0.94**	**--**
Level of significant	**0.05**	**--**
CV%	**4.72**	**--**

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[T_1 = Biomax (Abamectin) 1.2EC @ 1.0 ml/L of water, T_2 = Antario (*Bacillus thuringiensis* and abamectin) @ 1.0 ml/L of water, T_3 = Spinomax (Spinosad) 45SC @ 0.5 ml/L of water, T_4 = Bioneem plus (Azadirachtin) 1.0EC @ 1.0 ml/L of water, T_5 = Fytomax (Potassium salt of fatty acid) @ 1.0 ml/L of water and T_6 = Untreated control]

CHAPTER V

SUMMARY AND CONCLUSION

The study was conducted at the experimental field, Sher-e-Bangla Agricultural University, Dhaka during the period of rabi season 10 November 2019 to 20 February 2020 to investigate the insect pests of lettuce (*Lactuca sativa* L.) and their management by biopesticides. Lettuce variety-BARI I was used as test crop in this experiment. The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. Six treatments, viz.; T_1= Abamectin @ 1.0 ml/L of water at 7 days interval, T_2= *Bacillus thuringiensis* and abamectin @ 1.0 ml/L of water at 7 days interval, T_3= Spinosad @ 0.5 ml/L of water at 7 days interval), T_4= Azadirachtin @ 1.0 ml/L of water at 7 days interval, T_5= Potassium salt of fatty acid @ 1.0 ml/L of water at 7 days interval and T_6= untreated control) were used. Data was recorded on pest incidence, leaf infestation due to different insect pests and significant variation was observed for different studied characters due to different treatments.

Six insect pests such as flea beetle, tobacco caterpillar, jute hairy caterpillar, aphid, grasshopper and red pumpkin beetle were recorded from the lettuce crops in the field. In case of flea beetle, the highest number of healthy leaves/plant (26.27) was observed in T_3, whereas the lowest number (21.24) was recorded in T_5. The lowest number of infested leaves/plant (3.11) was found in T_3 treatment, whereas the highest number of infested leaves/plant (8.35) was found in T_6. The lowest infestation of leaves/plant (10.70%) was recorded in T_3 treatment, while the highest infestation (26.93%) was observed in T_6. In leaf infestation percentage reduction over control the highest value (60.27%) was recorded in T_3 and the lowest value (13.63%) from T_5 treatment.

In case of tobacco caterpillar, the highest number of healthy leaves/plant (24.38) was observed in T_3, whereas the lowest number (19.19) was recorded in T_2. The lowest number of infested leaves/plant (1.19) was found in T_3 treatment, whereas the highest number of infested leaves/plant (5.20) was found in T_6. The lowest infestation of leaves/plant (4.67%) was recorded in T_3 treatment, while the highest infestation (18.81%) was observed in T_6. In leaf infestation percentage reduction over control the highest value (75.17%) was recorded in T_3 and the lowest value (23.18%) from T_5 treatment.

In case of aphid, the highest number of healthy leaves/plant (24.46) was observed in T_3, whereas the lowest number (20.15) was recorded in T_5. The lowest number of infested leaves/plant (1.22) was found in T_3 treatment, whereas the highest number of infested leaves/plant (4.71) was found in T_6. The lowest infestation of leaves/plant (4.76%) was recorded in T_3 treatment, while the highest infestation (18.22%) was observed in T_6. In leaf infestation percentage reduction over control the highest value (73.87%) was recorded in T_3 and the lowest value (31.34%) from T_5 treatment.

In case of grasshopper, the highest number of healthy leaves/plant (23.40) was observed in T_3, whereas the lowest number (19.35) was recorded in T_6. The lowest number of infested leaves/plant (1.24) was found in T_3 treatment, whereas the highest number of infested leaves/plant (6.47) was found in T_6. The lowest infestation of leaves/plant (5.03%) was recorded in T_3 treatment, while the highest infestation (24.70%) was observed in T_6. In leaf infestation percentage reduction over control the highest value (79.64%) was recorded in T_3 and the lowest value (38.66%) from T_5 treatment.

In case of jute hairy caterpillar, the highest number of healthy leaves/plant (23.48) was observed in T_3, whereas the lowest number (19.42) was recorded in T_2. The lowest number of infested leaves/plant (1.25) was found in T_3 treatment, whereas the highest number of infested leaves/plant (11.85) was found in T_6. The lowest infestation of leaves/plant (5.07%) was recorded in T_3 treatment, while the highest infestation (37.67%) was observed in T_6. In leaf infestation percentage reduction over control the highest value (86.54%) was recorded in T_3 and the lowest value (51.34%) from T_5 treatment.

Again, during harvesting period the lowest leaf infestation intensity (8.64%), highest single plant weight (0.91 kg), healthy plant weight (0.76 kg plant-1) and highest total yield (16.43 ton ha^{-1}) were observed in T_3 where the highest leaf infestation intensity (21.50%), Lowest single plant weight (0.24 kg), healthy plant weight (0.29 kg plant-1) and lowest total yield (7.08 ton ha^{-1}) were obtained from T_6. But in the treated plots, the highest leaf infestation intensity (14.80%) was obtained from T_5 treatment. lowest single plant weight (0.42 kg) was obtained from T_4 treatment, healthy plant weight (0.42 kg plant-1) was obtained from T_4 and lowest total yield (14.13 ton ha^{-1}) were obtained from T_5 treatment.

From the above results, it may be concluded that, the treatment T_3 comprised of Spinosad 45SC @ 0.5 ml/L of water at 7 days interval gave the highest performance compared to all other treatments used under the present study where the lowest performance was achieved by untreated control. On the other hand, the lowest performance among the treated plots was obtained by T_5 (Potassium salt of fatty acid @ 1.0 ml/L of water at 7 days interval).

RECOMMENDATIONS

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

- ❖ Spinosad 45SC is the most effective biorational for the management of insect pests of lettuce in field and it might be incorporated for the development of integrated pest management (IPM) practices.
- ❖ Further trials should be done in the farmer’s field at different locations for the confirmation of the results.
- ❖ New biorationals may be included in future for the management of insect pests of lettuce.

CAHATER VI

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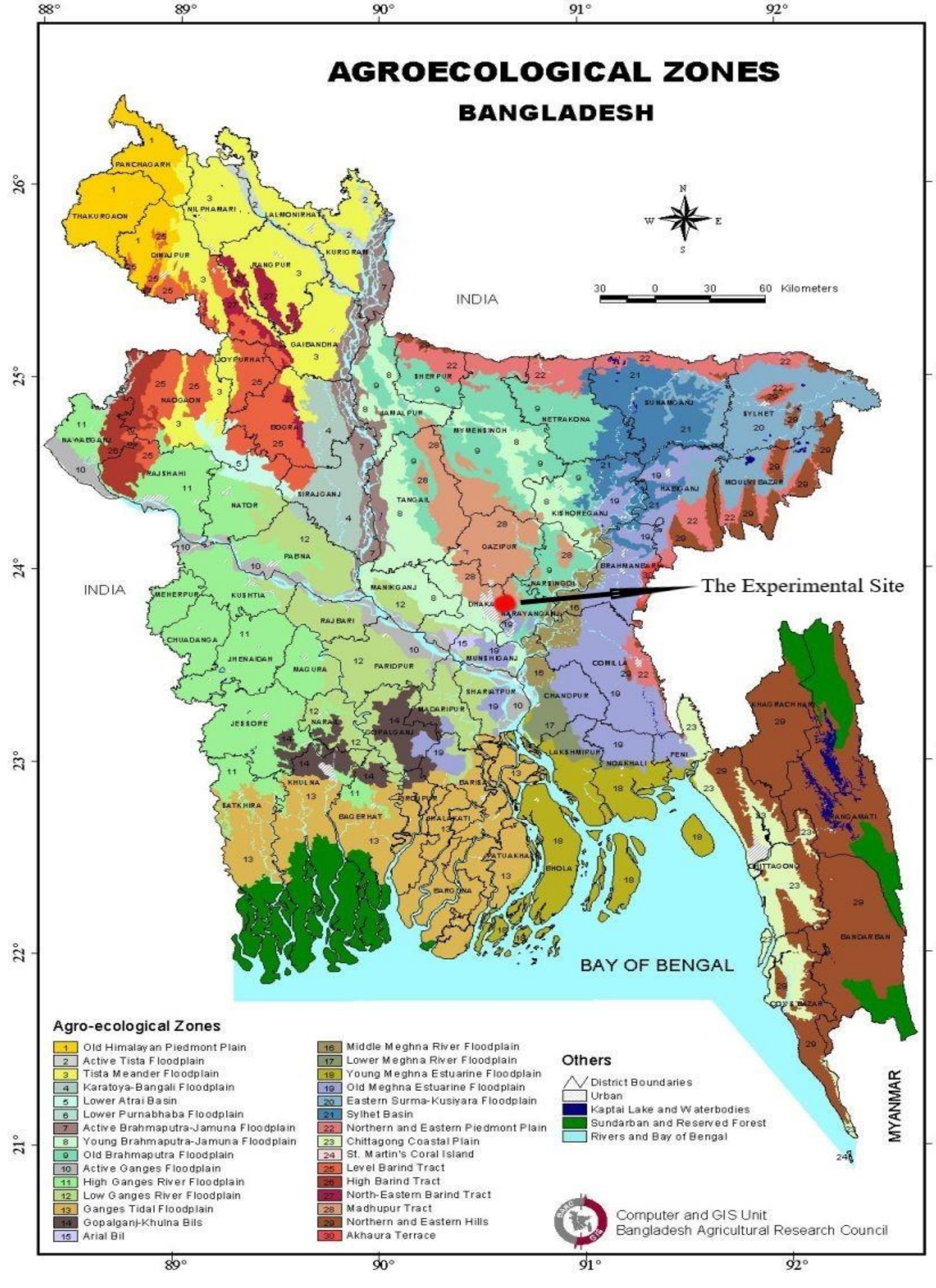
APPENDICES

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



Appendix II. Monthly average air temperature, relative humidity, rainfall and sunshine hours during the experimental period (10 November 2019 to 20 February 2020) at Sher - e - Bangla Agricultural University campus.

Month	Air temperature(^{0}C)		Relative humidity (%)	Rainfall (mm) (total)	Sunshine (hr)
	Maximum	Minimum			
October, 2019	29.3	10.12	70.44	16.22	6
November,2019	28.6	8.52	56.75	14.4	8
December,2019	25.5	6.7	54.8	0	9
January,2020	23.28	11.7	46.2	0	9
February,2020	22.75	14.26	37.9	0	8
March,2020	31.22	24.33	75.22	50	7

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

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

Soil characteristics	**Analytical result**
Agrological zone	Madhupur Tract
PH	5.47-5.63
Organic matter	0.82
Total N (%)	0.43
Available phosphorus	22 ppm
Exchangeable K	0.42meq/ 100 g soil

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