DEVELOPMENT OF INTEGRATED PEST MANAGEMENT PACKAGES AGAINST *SPODOPTERA LITURA* (FABRICIUS) IN TROPICAL SUGARBEET

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This is to certify that Dissertation entitled "**DEVELOPMENT OF INTEGRATED PEST MANAGEMENT PACKAGES AGAINST *SPODOPTERA LITURA* (FABRICIUS) IN TROPICAL SUGARBEET"** submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka-1207, in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY IN ENTOMOLOGY** embodies the result of a piece of bonafide research work carried out by **MUHAMMAD ABU TALHA**, Registration No. 27588/00743 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 the investigation has been duly acknowledged by him.

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TO

MY BELOVED

PARENTS

BIOGRAPHICAL SKETCH

The author, was born on June 15, 1980 in the district of Rajbari, Bangladesh. He is the 4th son of Mr. Ahammad Ali Shaikh and Mrs. Fatema Begum. He passed his SSC examination from Goalondo Najir Uddin Govt. Pilot High School, Rajbari in 1996 under Dhaka Board and HSC examination from Government Rajbari College, Rajbari under the same Board in 1998 and secured first division in both the examinations. He obtained his B.Sc.Ag. (Hons.) in 2003 (held in 2005) from Sher-e-Bangla Agricultural University (SAU), Dhaka and got first class. He did M.S. in Entomology under the Department of Entomology from the same University in 2007 and secured GPA 3.57 out of 4.00. During his M.S. degree, he worked on "Management of Whitefly (*Bemisia tabaci* Gennadius) in Tomato". He enrolled at the Sher-e-Bangla Agricultural University (SAU) in January-June, 2016 semester as a Ph.D. Fellow in the Department of Entomology. He completed 32 credit hours of course works and seminar as well as 30 credit hours of Dissertation Research.

After obtaining M.S. degree in Entomology, the author joined in the Division of Cane Development and Research at Bangladesh Sugar and Food Industries Corporation (BSFIC) as an Assistant Manager (Seed Inspection) on February 19, 2011. At present, he is serving as Deputy Manager (Seed Inspection and Agronomy) in the Carew and Company (Bangladesh) Limited, Darsana, Chuadanga (an enterprise of BSFIC). He is happily married to Rukaiya Saima and blessed with two sons, Muhammad Labib Hasan Rafe and Muhammad Abid Hasan Rayian.

ABBREVIATIONSANDACRONYMS

%	:	Percent
µL	:	microliter
a.i.	:	Active Ingredient
AGA	:	Alcohol-glycerin-aceticacid
BARC	:	Bangladesh Agricultural Research Council
BBS	:	Bangladesh Bureau of Statistics
BARI	:	Bangladesh Agricultural Research Institute
BINA	:	Bangladesh Institute of Nuclear Agriculture
BSFIC	:	Bangladesh Sugar and Food Industries Corporation
BSMRAU	:	Bangabandhu Sheikh Mujibur Rahman Agricultural University
BSRI	:	Bangladesh Sugarcrop Research Institute
CABI	:	Center for Agriculture and Bioscience International
CSGI	:	Seed Growers Association
CV	:	Coefficient of variation
cm	:	Centimeter
DAA	:	Days after Application
DAS	:	Days after Sowing
DMRT	:	Duncans' Multiple Range Test
DNA	:	Deoxyribo-nucleic acid
DPPH	:	2, 2-diphenyl-1-picrylhydrazyl
EC	:	Emulsifiable Concentrate
et al.	:	and others
etc.	:	Etcetra
ETL	:	Economic threshold
EU	:	European Union
FAO	:	Food and Agricultural Organization
FS	:	Flowable concentration for seed treatment
FYT	:	Final yield trial

ABBREVIATIONS AND ACRONYMS

g	:	Gram
IPPC	:	International Plant Protection Convention
IPM	:	Integrated Pest Management
J.	:	Journal
L: D	:	Light: Dark
LAI	:	Leaf area index
MS	:	Microsoft
NSKE	:	Need Seed Kernel Extract
nm	:	Nanometer
OD	:	Optical density
P	:	Phosphorous
p^H	:	Hydrogen ion concentration
RCBD	:	Randomized Complete Block Design
RH	:	Relative Humidity
SAU	:	Sher-e-Bangla Agricultural University
SC	:	Soluble Concentration
SE	:	Standard Error
SL	:	Soluble liquid
SMW	:	Standard Materological Week
$\bar{}Sx$	:	Standard error of the mean
T	:	Temperature
TS	:	Top Shoot
TTL	:	Top Trifoliate Leaf
USDA	:	United States Department of Agriculture
UV	:	UltraViolet
V	:	Volume
w	:	Weight
WAS	:	Weeks after Sowing
WG	:	Wettable Granule
WP	:	Wettable Powder/Water Dispersible Powder

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SAU, Dhaka

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ABSTRACT

Muhammad Abu Talha

Five experiments were conducted of which one in the laboratory of Entomology division of Bangladesh Sugar crop Research Institute and four in the experimental field of Sher-e-Bangla Agricultural University during November 2017 to May 2021. In the first experiment, we screened resistant sugarbeet varieties against *Spodoptera litura* and also asses the level of sugarbeet leaf and beet infestations caused by *S.litura*.The result showed that Cauvery was a best suited variety and PAC-60008 was most susceptible variety against *S.litura*. The highest (7.73) number of bore/plant and maximum (14.66) larvae were found in PAC-60008 variety while the lowest (2.20) number of bore/plant and minimum (2.00) larvae were observed in Cauvery variety. The yield of sugarbeet and its related parameters showed positive to Cauvery variety and negative to PAC-60008 variety. The highest yield 89.96 t ha-^{1} was found in Cauvery and the lowest yield 76.06 t ha-^{1} was found in PAC-60008 variety. The Brix (18.23%) and Pol (13.45%) was highest in Cauvery and lowest (brix-14.70%, pol-11.18%) in PAC-60008. An integrated management for *S. litura* control is indoor residual spraying (IRS) that represents one of the main tools for evaluation of effectiveness of insecticides on different life stages of *S. litura* under laboratory condition. The lowest days of adult emergence and weight of larvae were found (19±0.5) days and (17.8±0.8) mg at T6 (Nitro 505EC solution @ 2.0 ml/lit of water) treatment. The highest (92.5 %) mortality at 3rd instar larvae of *S. litura* was found at T_6 treatment. To identify the most effective insecticides for managing *S. litura* in tropical sugarbeet and determine the effective dose of insecticides to control the pest an experiment was conducted at field condition. As a result the T_3 (Nitro 505EC) and T_5 treatment (Virtako 40 WG) was the best suited and effective treatment against insect larvae compared to other. In order to evaluation the effectiveness of botanicals and non-chemical approaches against *S. litura* and find out the eco-friendly management practices an experiment was conducted at field level. The T_1 treatment (Neem Oil @ 3.0 ml/ lit of water) was showed the most effective treatment in this experiment. Finally, an integrate approaches for the best possible combinations of the tools identified from the previous experiment as effective against *S. litura* for safe and hazards free tropical sugarbeet production. The T_{10} treatment (Pheromone trap + Hand Picking + Nitro 505EC) was the best suited treatment. The highest (78.43 %) efficacy was observed in T_{10} treatment as compared to other. The highest Brix (19.50 %) and the Pol (12.00 %) were found in T_{10} treated plots followed by 18.66 % Brix and 11.83 % Pol were found in T_9 treatment. The highest (814.67 g) individual beet weight was found in T_{10} treated plot followed by 807.33 g in T_9 (pheromone trap + hand picking + Virtako 40WG) where as the lowest individual beet weight was 722.67 g in T_{11} (control) plot. It indicates that as the pest infestation increased so decreased the beet yield.

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CHAPTER I

INTRODUCTION

Tropical sugarbeet, *Beta vulgaris* L., a temperate crop under family of Chenopodiaceae (Amaranthaceae) is the second important sugar crop after sugarcane, producing about 35-40% of sugar annually all over the world (Amr and Gaffer, 2010 and Wu *et. al.*,2016) and recently sugarbeet is becoming an important biofuel alternative to fossil fuel energy (Zhang *et a1.*, 2008). Kapur and Kanwar (1990) stated that sugarbeet can be grown successfully as a winter crop in subtropics or subtropical region. It is widely distributed throughout the tropical and temperate Asia, Australia, Sudan, Pakistan and the Pacific islands. Sugarbeet processing can be done from 270 to 300 days per year (Asadi, 2007). Now sugarbeet varieties are being cultivated successfully in tropical and subtropical countries including India, Pakistan and Bangladesh. Wide agro-climatic diversity of Bangladesh is suitable for sugarbeet cultivation including saline areas. For balanced human diet, 13kg sugar or 17 kg 'goor' per capita are required and as such our requirement is about 2.08 million tons but we produced of 0.15 million tons and 0.40 million tons of sugar and goor respectively (Anon., 2004). Sugarbeet can produce 2-3 times higher sugar yields per hectare in a short period (4-6 months) as compared to sugarcane which needs 12-16 months (Baloach *et. al.*, 2002). Therefore, the shortage of sugar/goor may be covered through cultivation of sugarbeet to achieve the requirement and to uplift economic condition of Bangladesh.

Population increase as well as urbanization, demands of sugar is being increased, while acreage of sugarcane cultivation is being gradually decreased due to higher demand for cereals, vegetables, etc. and utilization of crop lands for houses,

roads, industries, etc. Therefore, there is no scope to increase sugarcane acreage to meet the higher demand of increasing population in Bangladesh. To fulfill our sugar shortage, Bangladesh imports about 3-5 million tons of sugar annually which is not only huge financial burden on the national exchequer but also an emerging threat to the sugar industry and related beneficiaries, i.e. mainly farmers and indirect stakeholders in the country.

Since sugarcane is a long duration crop thus farmers are moving to grow short duration crop for higher profit. Therefore, in Bangladesh, most of the sugar mills remain unproductive for a particular period of time due to acute shortage of supply of sugarcane to the mills in proper time.

In this regard, sugarbeet might be an excellent alternative of sugarcane if processing facilities are developed in the sugar mills. Before that, feasibility study for sugarbeet cultivation in Bangladesh need to be assessed properly. Meanwhile, no systematic research work has so far been done in Bangladesh. So, sugarbeet cultivation may be miracle for us if we can cultivate it properly with proper technology. Because, it contains higher sugar (14-20%) than sugarcane and requires less duration (5-6 months) (Anon., 2004).

To meet increasing needs of sugar, all aspects of producing the crop efficiently should be widely researched, and work continues rapidly in all countries where they grown. Bangladesh has immense potentiality for sugarbeet cultivation which may take the production of sugar to a satisfactory level.

Being a new crop, several constraints are noticed in cultivation of sugarbeet among them severe incidence of insect pests and diseases is a major one (Patil *et. al.,* 2007).

Sugarbeet insect pests can cause yield loss of 18 t ha^{-1}. Insect pest is one of the main problems for sugarbeet production in Bangladesh. Eight insect pests' *viz.,* sugarbeet caterpillar, cutworm, aphids, red mite, grasshopper, hairy caterpillar, flea beetle and webworm have been reported. Sugarbeet caterpillar, *Spodoptera litura* is the most destructive pests of sugarbeet (Nakasuji and Mastsuzaki, 1976). This caterpillar is a cosmopolitan and polyphagous pest, affecting several crops like cotton, pulses, oil seeds, vegetables, ornamental plants and weed species as well (Zhou *et a1.,* 2010 and Navasero, 2011).

Spodoptera litura is an extremely serious insect pest, the larvae of which can defoliate many economically important crops. It is seasonally common in annual and perennial agricultural systems in tropical and temperate Asia. This noctuid is often found as part of a complex of lepidopteran and non-lepidopteran foliar feeders but may also injure tubers and roots. Hosts include field crops grown for food and fiber, plantation and forestry crops, as well as certain weed species (CABI, 2010).

Female adult moths lay eggs in masses on the lower surface of leaves. The eggs hatch in about 6-8 days. Soon after hatching, the young larvae start feeding on the epidermis of the leaves. Initially, the caterpillars are translucent green with a dark thorax. They feed gregariously in the early stages and damaged leaves appear skeletonized. The larger caterpillar is voracious feeder which consumes 10-15 g day^{-1} and the crop may be completely defoliated within a week (Seth *et al.*, 2004). Two, four and eight larvae per plant reduced sugarbeet yield by 24, 44.2 and 50.4%, respectively (Patel *et. a1.,* 1971). Larvae also attacked exposed tubers when young succulent leaves are unavailable. Up to 2% of tubers were damaged in August-September and February (Trivedi,

1988). *Spodoptera litura* is also a destructive pest of sugarbeet, with infestations commencing in March and peaking in late March and April (Chatterjee and Nayak, 1987 and Iqbal *et a1.*, 2015). Severe infestations led to skeletonisation of leaves as well as feeding holes in roots that rendered the crop virtually unfit for marketing. Late harvested crops are most severely affected and in extreme cases about 100% of the roots are damaged, leading to considerable yield reduction.

Different pest management practices like resistant varieties, cultural practices, mechanical control, and biological and chemical control methods have so far been recommended to control sugarbeet caterpillar. But no single method had so far been proved to be completely successful and reliable. Among all these methods, the chemical control method is still popular to our farmers because of its quick and visible actions. Frequent and the large-scale use of synthetic pesticides in agriculture have developed pesticide resistance, frequent pest outbreaks, emergence of new pests, environmental pollution and human health hazards.

To find out the alternate effective method for controlling a particular pest, it is absolutely necessary to know the biology and ecology of the pest, its habit and habitats, its food and feeding pattern, etc. So, to determine the most vulnerable stage in its life cycle at which the particular insect can be killed very easily. In Bangladesh, sufficient information on sugarbeet caterpillar *Spodoptera litura* for its management is not available and no in-depth studies have been made till date.

The integrated Pest Management (lPM) is the most desired approach because it is the management of the insect pests by using more than one possible echnique in such a way that the damage is kept below the economic injury level through least affecting the

environment. The comparative efficacy of different management tactics including some non-chemical and selected insecticides for development of suitable integrated pest management approach using safer components are not properly addressed in Bangladesh.

Under these perspectives, application of the integrated management packages thought to be eco-friendly components for the management of *Spodoptera litura*. Therefore, the present study was planned and designed with the following objectives:

1. To identify the resistant or least preferred tropical sugarbeet variety(ies) against sugarbeet caterpillar;
2. To evaluate different life stages of sugarbeet caterpillar against the promising insecticides under laboratory and field conditions;
3. To find out the efficacy of botanicals and other non-chemical management practices against infestation of sugarbeet caterpillar in field condition;
4. To determine the effective chemical insecticides against the sugarbeet caterpillar for commercial cultivation of tropical sugarbeet in Bangladesh and
5. To develop integrated management approaches by incorporating non-chemical approaches, and some selected insecticides against *Spodoptera litura* infestation of tropical sugarbeet.

CHAPTER II

REVIEW OF LITERATURE

The root of sugarbeet contains of high concentration of sucrose and is grown commercially for sugar production. In plant breeding it is known as the Altissima cultivar group of the common beet (*Beta vulgaris*). Together with other beet cultivars, such as beet root and chard, it belongs to the sub species *Beta vulgaris* sub sp. *vulgaris*. Its closest wild relative is the sea beet (*Beta vulgaris* sub sp. *maritima*).

In 2013, Russia, France, the United States, Germany and Turkey were the world's five largest sugar beet producers. North America and Europe did not produce enough sugar from sugar beets to meet overall demand for sugar and were all net importers of sugar. The US harvested 1,004,600 acres (406,547 ha) of sugar beets in 2008 (USDA, 2008). In 2009, sugar beets accounted for 20% of the world's sugar production (FAO, 2009).

2.1 Description

The sugarbeet has a conical, white, fleshy root (a taproot) with a flat crown. The plant consists of the root and a rosette of leaves. Sugar is formed by photosynthesis in the leaves and is then stored in the root.

The root of the beet contains 75% water, about 20% sugar, and 5% pulp (Anon, 1999). The exact sugar content can vary between 12% and 21% sugar, depending on the cultivar and growing conditions. Sugar is the primary value of sugar beet as a cash crop. The pulp, insoluble in water and mainly composed of cellulose, hemicellulose, lignin,

and pectin, is used in animal feed. The byproducts of the sugar beet crop, such as pulp and molasses, add another 10% to the value of the harvest (FAO, 2009).

Sugar beets grow exclusively in the temperate zone, in contrast to sugarcane, which grows exclusively in the tropical and subtropical zones. The average weight of sugar beet ranges between 0.5 and 1 kg (1.1 and 2.2 lb.). Sugar beet foliage has a rich, brilliant green color and grows to a height of about 35 cm (14 in). The leaves are numerous and broad and grow in a tuft from the crown of the beet, which is usually level with or just above the ground surface (George, 1873).

2.2 History

Modern sugar beets date back to mid-18th century Silesia where the king of Prussia subsidized experiments aimed at processes for sugar extraction (Hill and Langer (1991). In 1747, Andreas Marggraf isolated sugar from beet roots and found them at concentrations of 1.3–1.6% (Hanelt *et al.,* 2001). He also demonstrated that sugar could be extracted from beets that was identical with sugar produced from sugarcane. (Sugarbeet Archived, 2009). His student, Franz Karl Achard, evaluated 23 varieties of mangelwurzel for sugar content and selected a local strain from Halberstadt in modern-day Saxony-Anhalt, Germany. Moritz Baron von Koppy and his son further selected from this strain for white, conical tubers (Hanelt *et al.,* 2001). The selection was named *weiße schlesische Zuckerrübe*, meaning white Silesian sugar beet, and boasted about a 6% sugar content (Hill and Langer (1991), Hanelt *et al.,* 2001). This selection is the progenitor of all modern sugarbeets (Hanelt *et al.,* 2001).

A royal decree led to the first factory devoted to sugar extraction from beetroots being opened in Kunern, Silesia (now Konary, Poland) in 1801. The Silesian sugarbeet was soon introduced to France, where Napoleon opened schools specifically for studying the plant. He also ordered that 28,000 hectares (69,000 acres) be devoted to growing the new sugar beet (Hill and Langer (1991). This was in response to British blockades of cane sugar during the Napoleonic Wars, which ultimately stimulated the rapid growth of a European sugar beet industry (Hill and Langer (1991). By 1840, about 5% of the world's sugar was derived from sugar beets, and by 1880, this number had risen more than tenfold to over 50% (Hill and Langer, (1991). The sugarbeet was introduced to North America after 1830, with the first commercial production starting in 1879 at a farm in Alvarado, California. The sugarbeet was also introduced to Chile by German settlers around 1850 (Hanelt *et al.*, 2001).

2.3 Creation

The beet-root, when being boiled, yields a juice similar to syrup of sugar, which is beautiful to look at on account of its vermilion color (Jules, 1912). This was written by 16th-century scientist, Olivier de Serres, who discovered a process for preparing sugar syrup from the common red beet. However, because crystallized cane sugar was already available and provided a better taste, this process never caught on. This story characterizes the history of the sugarbeet. The competition between beet sugar and sugarcane for control of the sugar market plays out from the first extraction of sugar syrup from a garden beet into the modern day.

The use of sugarbeets for the extraction of crystallized sugar dates to 1747, when Andreas Sigismund Marggraf, Professor of Physics in the Academy of Science of Berlin,

discovered the existence of a sugar in vegetables similar in its properties to that obtained from sugarcane. He found the best of these vegetable sources for the extraction of sugar was the white beet. Despite Marggraf’s success in isolating pure sugar from beets, their commercial manufacture for sugar did not take off until the early 19th century. Marggraf's student and successor Franz Karl Achard began selectively breeding sugarbeet from the 'White Silesian' fodder beet in 1784. By the beginning of the 19th century, his beet was about 5–6% sucrose by (dry) weight, compared to around 20% in modern varieties. Under the patronage of Frederick William III of Prussia, he opened the world's first beet sugar factory in 1801, at Cunern (Polish: Konary) in Silesia (George, 1873).

2.3.1. France

The work of Achard soon attracted the attention of Napoleon Bonaparte, who appointed a commission of scientists to go to Silesia to investigate Achard's factory. Upon their return, two small factories were constructed near Paris. Although these factories were not altogether a success, the results attained greatly interested Napoleon. Thus, when two events, the blockade of Europe by the British Navy and the Haitian Revolution, made the importation of cane sugar untenable, Napoleon seized the opportunity offered by beet sugar to address the shortage. In 1811, Napoleon issued a decree appropriating one million francs for the establishment of sugar schools, and compelling the farmers to plant a large acreage to sugar beets the following year. He also prohibited the further importation of sugar from the Caribbean effective in 1813 (Dowling, 1928).

The number of mills increased considerably during the 1820s and 1830s, reaching a peak of 543 in 1837. The number was down to 382 in 1842, producing about 22.5 million kg of sugar during that year.

2.3.2. Western Europe

As a result of the French advances in sugar beet production and processing made during the Napoleonic Wars, the beet sugar industry in Europe developed rapidly. A new tax levied in Germany in 1810 prompted the experimentation to increase the sugar content of the beet. This was because the tax assessed the value of the sugar beet crop based on the unprocessed weight of the sugar beet rather than the refined sugar produced from them (Dowling, 1928; Poggi, 1930). By 1812, Frenchman Jean-Baptiste Quéruel, working for the industrialist Benjamin Delessert, devised a process of sugar extraction suitable for industrial application. By 1837, France had become the largest sugarbeet producer in the world, a position it continued to hold in the world even into 2010. By 1837, 542 factories in France were producing 35,000 tons of sugar. However, by 1880, Germany became the largest producer of sugar from sugarbeet in the world, since the German factories processed most of the sugarbeets grown in eastern France (George, 1873).

By the 1850s, sugarbeet production had reached Russia and Ukraine. This was made possible by the protection of the sugarbeet industry by bounties, or subsidies, paid to beet sugar producers upon the export of their sugar by their respective governments (Dowling, 1928). The protection provided to the sugarbeet industry by these bounties caused drastic damage to the cane sugar industry and their grip on the British sugar market. The result was a reduction in the production of cane sugar, molasses and rum until 1915 (Dowling, 1928). During World War I, the widespread conflict destroyed large tracts of land that had served as sugarbeet producers and repurposed much of the remaining sugarbeet land for grain production. This resulted in a shortage that revived the shrinking cane sugar industry (Dowling, 1928).

2.3.3. United States

The first attempts at sugarbeet cultivation were pursued by abolitionists in New England. The "Beet Sugar Society of Philadelphia" was founded in 1836 and promoted home-produced beet sugar as an alternative to the slave-produced cane sugar from the West Indies or sugar imported from Asia (called "free sugar" because it was grown without using slavery), but which tasted "awful". However, this movement failed, perhaps most due to the unpopularity of abolitionists at the time, at least until the Civil War, when these associations would become irrelevant and only the economic feasibility of the industry remained (Kaufman, 2008)

In the 1850s, an attempt was made in Utah by the LDS Church-owned Deseret Manufacturing Company to grow and process sugarbeets that failed for several reasons. First, the beet seeds they imported from France were not able to produce much sugar in the heavily salinized soil of Utah. Second, the cost of importing the beet seed from France ate up any possibility for profit. Finally, none of the people running the factory knew how to properly use the chemicals to separate the sugar from the beet pulp (Robert, 2014).

The first successful sugarbeet factory was built by E. H. Dyer at Alvarado, California (now Union City), in 1870, but did not see any profit until 1879. The factory survived on subsidies it gained, since the abolitionist stigma that had held back the development of a sugarbeet industry had been erased with the Civil War (Kaufman, 2008; Robert, 2014; Magnuson, 1918). After this first success in Alvarado, the sugarbeet industry expanded rapidly. Research done by Rachel Lloyd at the University of Nebraska in the late 1880's resulted in a large production increase in the state of Nebraska. In 1889, Arthur

Stayner and others were able to convince LDS Church leaders to back a second attempt, leading to the Utah-Idaho Sugar Company (Arrington, 1966; Godfrey, 2007)

But capital investment in factories demanded adequate supply of sugarbeets. In central Colorado and western Nebraska, this was provided substantially by Germans from Russia who were already expert at sugarbeet farming when they immigrated in large numbers ca 1890 - 1905.

By 1914, the sugarbeet industry in the United States matched the production of its European counterparts. The largest producers of beet sugar in the United States would remain California, Utah, and Nebraska until the outbreak of World War II (Magnuson, 1918; Taussig, 1912). In California were Japanese Americans; when they were interned during World War II, California's beet sugar production also shifted inland to states such as Idaho, Montana, North Dakota, and Utah. In many of the regions where new sugarbeet farms were started during the war, farmers were unfamiliar with beet sugar cultivation, so they hired Japanese workers from internment camps who were familiar with sugarbeet production to work on the farms (Fiset, 1999).

Sugarbeets are grown in 11 states and represent 55% of the US sugar production as compared to sugarcane which is grown in 4 states and accounts for 45% of US sugar production.

2.3.4. United Kingdom

Sugarbeets were not grown on a large scale in the United Kingdom until the mid-1920s, when 17 processing factories were built, following war-time shortages of imported cane sugar. Before World War I, with its far-flung empire, the United Kingdom simply

imported the sugar from the cheapest market. However, World War I had created a shortage in sugar, prompting the development of a domestic market. The first sugarbeet processing factory was built at Lavenham in Suffolk in 1860, but failed after a few years without the government support its counterparts on the continent received. The Dutch built the first successful factory at Cantley in Norfolk in 1912, and it was moderately successful since, because of its Dutch backing, it received Dutch bounties (Dowling, 1928).

Sugarbeet seed from France was listed in the annual catalogues of Gartons Agricultural Plant Breeders from that firm's inception in 1898 until the first of their own varieties was introduced in 1909. In 1915, the British Sugarbeet Society was formed to create an example of a domestic sugarbeet industry for the purpose of obtaining government financing. Twelve years later, in 1927, they succeeded. The sugarbeet industry in the United Kingdom was finally subsidized providing stability to the domestic industry that had experienced volatile shifts in profits and losses in the years since 1915 (Dowling, 1928).

2.3.5. Russia

References to the sugar manufacturing from beets in Russia are dating back to 1802. Jacob Esipov has built a first Russian commercial factory producing sugar from beets in the Tula province.

During the Soviet period, some particularly impressive advancement were made in seed development, of which the most useful was the development of a frost-resistant sugar beet, further expanding the growing range of the sugarbeet (Buzanov, 1967).

2.4. Culture

The sugarbeet, like sugarcane, needs a peculiar soil and a unique climate for its successful cultivation. The most important requirement is the soil must contain a large supply of plant food, be rich in humus, and have the property of retaining a great deal of moisture. A certain amount of alkali is not necessarily detrimental, as sugarbeets are not especially susceptible to injury by some alkali. The ground should be fairly level and well-drained, especially where irrigation is practiced (George, 1873).

While the physical character is of secondary importance, as generous crops are grown in sandy soil as well as in heavy loams, still the ideal soil is a sandy loam, i.e., a mixture of organic matter, clay and sand. A subsoil of gravel, or the presence of hard-pan, is not desirable, as cultivation to a depth of from 12 to 15 inches (30.5 to 38.1 cm) is necessary to produce the best results.

Climatic conditions, temperature, sunshine, rainfall and winds have an important bearing upon the success of sugarbeet agriculture. A temperature ranging from 15 to 21 °C (59.0 to 69.8 °F) during the growing months is most favorable. In the absence of adequate irrigation, 460 mm (18.1 inches) of rainfall are necessary to raise an average crop. High winds are harmful, as they generally crust the land and prevent the young beets from coming through the ground. The best results are obtained along the coast of southern California, where warm, sunny days succeeded by cool, foggy nights seem to meet sugar beet's favored growth conditions. Sunshine of long duration but not of great intensity is the most important factor in the successful cultivation of sugarbeets. Near the equator, the shorter days and the greater heat of the sun sharply reduce the sugar content in the beet (George, 1873).

In high elevation regions such as those of Colorado and Utah, where the temperature is high during the daytime, but where the nights are cool, the quality of the sugarbeet is excellent. In Michigan, the long summer days from the relatively high latitude (the Lower Peninsula, where production is concentrated, lies between the 41st and 46th parallels north) and the influence of the Great Lakes result in satisfactory climatic conditions for sugarbeet culture. Sebewaing, Michigan lies in the Thumb region of Michigan; both the region and state are major sugarbeet producers. Sebewaing is home to one of three Michigan Sugar Company factories. The town sponsors an annual Michigan Sugar Festival.

To cultivate beets successfully, the land must be properly prepared. Deep ploughing is the first principle of beet culture. It allows the roots to penetrate the subsoil without much obstruction, thereby preventing the beet from growing out of the ground, besides enabling it to extract considerable nourishment and moisture from the lower soil. If the latter is too hard, the roots will not penetrate it readily and, as a result, the plant will be pushed up and out of the earth during the process of growth. Hard subsoil is impervious to water and prevents proper drainage. It should not be too loose, however, as this allows the water to pass through more freely than is desirable. Ideally, the soil should be deep, fairly fine and easily penetrable by the roots. It should also be capable of retaining moisture and at the same time admit of a free circulation of air and good drainage. Sugarbeet crops exhaust the soil rapidly. Crop rotation is recommended and necessary. Normally, beets are grown in the same ground every third year, peas, beans or grain being raised the other two years (George, 1873).

In most temperate climates, beets are planted in the spring and harvested in the autumn. At the northern end of its range, growing seasons as short as 100 days can produce commercially viable sugarbeet crops. In warmer climates, such as in California's Imperial Valley, sugarbeets are a winter crop, planted in the autumn and harvested in the spring. In recent years, Syngenta has developed the so-called tropical sugarbeet. It allows the plant to grow in tropical and subtropical regions. Beets are planted from a small seed; 1 kg (2.2 lb.) of beet seed comprises 100,000 seeds and will plant over one hectare (2.5 acres) of ground (one pound or 0.454 kilograms will plant about one acre or 0.40 hectares.

Until the latter half of the 20th century, sugarbeet production was highly labor-intensive, as weed control was managed by densely planting the crop, which then had to be manually thinned two or three times with a hoe during the growing season. Harvesting also required many workers. Although the roots could be lifted by a plough-like device which could be pulled by a horse team, the rest of the preparation was by hand. One laborer grabbed the beets by their leaves, knocked them together to shake free loose soil, and then laid them in a row, root to one side, and greens to the other. A second worker equipped with a beet hook (a short-handled tool between a billhook and a sickle) followed behind, and would lift the beet and swiftly chop the crown and leaves from the root with a single action. Working this way, he would leave a row of beets that could be forked into the back of a cart.

Today, mechanical sowing, herbicide application for weed control, and mechanical harvesting have displaced this reliance on manual farm work. A root beater uses a series of blades to chop the leaf and crown (which is high in no sugar impurities) from the root. The beet harvester lifts the root, and removes excess soil from the root in a single pass

over the field. A modern harvester is typically able to cover six rows at the same time. The beets are dumped into trucks as the harvester rolls down the field, and then delivered to the factory. The conveyor then removes more soil.

If the beets are to be left for later delivery, they are formed into clamps. Straw bales are used to shield the beets from the weather. Provided the clamp is well built with the right amount of ventilation, the beets do not significantly deteriorate. Beets that freeze and then defrost produce complex carbohydrates that cause severe production problems in the factory.

In the UK, loads may be hand examined at the factory gate before being accepted. In the US, the fall harvest begins with the first hard frost, which arrests photosynthesis and the further growth of the root. Depending on the local climate, it may be carried out over the course of a few weeks or be prolonged throughout the winter months. The harvest and processing of the beet is referred to as "the campaign", reflecting the organization required to deliver the crop at a steady rate to processing factories that run 24 hours a day for the duration of the harvest and processing (for the UK, the campaign lasts about five months). In the Netherlands, this period is known as *de bietencampagne*, a time to be careful when driving on local roads in the area while the beets are being grown, because the naturally high clay content of the soil tends to cause slippery roads when soil falls from the trailers during transport.

2.5. Production

The world harvested 250,191,362 metric tons (246,200,000 long tons; 275,800,000 short tons) of sugarbeets in 2013. The world's largest producer was the United States, with a

39,321,161 metric tons (38,700,000 long tons; 43,300,000 short tons) harvest.The average yield of sugarbeet crops worldwide was 58.2 tons per hectare.

The most productive sugarbeet farms in the world, in 2010, were in Chile, with a nationwide average yield of 87.3 tons per hectare.

Imperial Valley (California) farmers have achieved yields of about 160 tons per hectare and over 26 tons sugar per hectare. Imperial Valley farms benefit from high intensities of incident sunlight and intensive use of irrigation and fertilizers (Limb, 2008).

The sugar industry in the EU came under bureaucratic pressure in 2006 and ultimately resulted in the loss of 20,000 jobs, although many factories, as detailed in a later 2010 EU audit, were found to have been mistakenly shut down, as they were profitable without government intervention. Western Europe and Eastern Europe did not produce enough sugar from sugarbeets to meet overall demand for sugar in 2010–2011, and were net importers of sugar.

After they are harvested, beets are typically transported to a factory. In the UK, beets are transported by a hauler, or by a tractor and a trailer by local farmers. Railways and boats are no longer used. Some beets were carried by rail in the Republic of Ireland, until the complete shutdown of Irish Sugar beet production in 2006.

Each load is weighed and sampled before it gets tipped onto the reception area, typically a "flat pad" of concrete, where it is moved into large heaps. The beet sample is checked for

- soil tare – the amount of non-beet delivered
- crown tare – the amount of low-sugar beet delivered

- sugar content ("pol") - amount of sucrose in the crop
- Nitrogen content – for recommending future fertilizer use to the farmer.

From these elements, the actual sugar content of the load is calculated and the grower's payment determined.

The beet is moved from the heaps into a central channel or gulley, where it is washed towards the processing plant.

After reception at the processing plant, the beet roots are washed, mechanically sliced into thin strips called cossettes, and passed to a machine called a diffuser to extract the sugar content into a water solution, a process known as leaching.

Diffusers are long vessels of many metres in which the beet slices go in one direction while hot water goes in the opposite direction. The movement may either be caused by a rotating screw or the whole rotating unit, and the water and cossettes move through internal chambers. The three common designs of diffuser are the horizontal rotating 'RT' *(Raffinerie Tirlemontoise*, manufacturer), inclined screw 'DDS' (*De Danske Sukkerfabrikker*), or vertical screw "Tower". Modern tower extraction plants have a processing capacity of up to 17,000 metric tons (16,700 long tons; 18,700 short tons) per day. A less-common design uses a moving belt of cossettes, with water pumped onto the top of the belt and poured through. In all cases, the flow rates of cossettes and water are in the ratio one to two. Typically, cossettes take about 90 minutes to pass through the diffuser, the water only 45 minutes. These countercurrent exchange methods extract more sugar from the cossettes using less water than if they merely sat in a hot water tank. The liquid exiting the diffuser is called raw juice. The color of raw juice varies from black to

a dark red depending on the amount of oxidation, which is itself dependent on diffuser design.

The used cossettes, or pulp, exit the diffuser at about 95% moisture, but low sucrose content. Using screw presses, the wet pulp is then pressed down to 75% moisture. This recovers additional sucrose in the liquid pressed out of the pulp, and reduces the energy needed to dry the pulp. The pressed pulp is dried and sold as animal feed, while the liquid pressed out of the pulp is combined with the raw juice, or more often introduced into the diffuser at the appropriate point in the countercurrent process. The final byproduct, vinasse, is used as fertilizer or growth substrate for yeast cultures.

During diffusion, a portion of the sucrose breaks down into invert sugars. These can undergo further breakdown into acids. These breakdown products are not only losses of sucrose, but also have knock-on effects reducing the final output of processed sugar from the factory. To limit (thermophilic) bacterial action, the feed water may be dosed with formaldehyde and control of the feed water pH is also practiced. Attempts at operating diffusion under alkaline conditions have been made, but the process has proven problematic. The improved sucrose extraction in the diffuser is offset by processing problems in the next stages.

Carbonatation is a procedure which removes impurities from raw juice before it undergoes crystallization (Koyikkal, 2013). First, the juice is mixed with hot milk of lime (a suspension of calcium hydroxide in water). This treatment precipitates a number of impurities, including multivalent anions such as sulfate, phosphate, citrate and oxalate, which precipitate as their calcium salts and large organic molecules such as proteins, saponins and pectins, which aggregate in the presence of multivalent cations.

In addition, the alkaline conditions convert the simple sugars, glucose and fructose, along with the amino acid glutamine, to chemically stable carboxylic acids. Left untreated, these sugars and amines would eventually frustrate crystallization of the sucrose.

Next, carbon dioxide is bubbled through the alkaline sugar solution, precipitating the lime as calcium carbonate (chalk). The chalk particles entrap some impurities and absorb others. A recycling process builds up the size of chalk particles and a natural flocculation occurs where the heavy particles settle out in tanks (clarifiers). A final addition of more carbon dioxide precipitates more calcium from solution; this is filtered off, leaving a cleaner, golden light-brown sugar solution called thin juice.

Before entering the next stage, the thin juice may receive soda ash to modify the pH and sulphitation with a sulfur-based compound to reduce color formation due to decomposition of monosaccharide under heat.

2.5.1. Evaporation

The thin juice is concentrated via multiple-effect evaporation to make a thick juice, roughly 60% sucrose by weight and similar in appearance to pancake syrup. Thick juice can be stored in tanks for later processing, reducing the load on the crystallization plant.

2.5.2. Crystallization

Thick juice is fed to the crystallizers. Recycled sugar is dissolved into it, and the resulting syrup is called mother liquor. The liquor is concentrated further by boiling under a vacuum in large vessels (the so-called vacuum pans) and seeded with fine sugar crystals. These crystals grow as sugar from the mother liquor forms around them. The resulting sugar crystal and syrup mix is called a *massecuite*, from "cooked mass" in French. The

massecuite is passed to a centrifuge, where the High Green syrup is removed from the massecuite by centrifugal force. After a predetermined time, water is then sprayed into the centrifuge via a spray bar to wash the sugar crystals which produces Low Green syrup. The centrifuge then spins at very high speed to partially dry the crystals the machine then slows down and a plough shaped arm is deployed which ploughs out the sugar from the sides of the centrifuge from the top to the bottom onto conveying plant underneath where it is transported into a rotating granulator where it is dried using warm air.

The high green syrup is fed to a raw sugar vacuum pan from which a second batch of sugar is produced. This sugar ("raw") is of lower quality with more color and impurities, and is the main source of the sugar dissolved again into the mother liquor. The syrup from the raw (Low green syrup) is boiled for a long time in AP Pans and sent to slowly flow around a series of about eight crystallizers. From this, a very low-quality sugar crystal is produced (known in some systems as "AP sugar") that is also dissolved. The syrup separated is molasses, which still contains sugar, but contains too much impurity to undergo further processing economically. The molasses is stored on site and is added to dried beet pulp to make animal feed. Some is also sold in bulk tankers.

Actual procedures may vary from the above description, with different recycling and crystallization processes.

2.5.3. Beverages

In a number of countries, notably the Czech Republic and Slovakia, beet sugar is used to make a rum-like distilled spirit called *Tuzemak.* On the Åland Islands, a similar drink is made under the brand name *Kobba Libre*. In some European countries, especially in the Czech Republic and Germany, beet sugar is also used to make rectified spirit and vodka.

2.5.4. Sugarbeet syrup

Unrefined sugary syrup can be produced directly from sugar beet. This thick, dark syrup is produced by cooking shredded sugarbeet for several hours, then pressing the resulting mash and concentrating the juice produced until it has a consistency similar to that of honey. No other ingredients are used. In Germany, particularly the Rhineland area, this sugar beet syrup (called *Zuckerrüben-Sirup* or *Zapp* in German) is used as a spread for sandwiches, as well as for sweetening sauces, cakes and desserts.

Commercially, if the syrup has a dextrose equivalency (DE) above 30, the product has to be hydrolyzed and converted to a high-fructose syrup, much like high-fructose corn syrup, or isoglucose syrup in the EU.

Many road authorities in North America use desugared beet molasses as de-icing or anti-icing products in winter control operations. The molasses can be used directly (Morrison, 2008), combined with liquid chlorides and applied to road surfaces, or used to treat the salt spread on roads (Peter, 2009). Molasses can be more advantageous than road salt alone because it reduces corrosion and lowers the freezing point of the salt-brine mix, so the de-icers remain effective at lower temperatures (Morrison, 2008). The addition of the liquid to rock salt has the additional benefits that it reduces the bounce and scatter of the

rock salt, keeping it where it is needed, and reduces the activation time of the salt to begin the melting process (Peter, 2009).

2.5.5. Betaine

Betaine can be isolated from the byproducts of sugar beet processing. Production is chiefly through chromatographic separation, using techniques such as the "simulated moving bed".

2.5.6. Uridine

Uridine can be isolated from sugar beet.

2.5.7. Alternative fuel

BP and Associated British Foods plan to use agricultural surpluses of sugar beet to produce biobutanol in East Anglia in the United Kingdom. The feedstock-to-yield ratio for sugarbeet is 56:9. Therefore, it takes 6.22 kg of sugar beet to produce 1 kg of ethanol (approximately 1.27 liter at room temperature).

2.5.8. Agriculture

Sugar beets are an important part of a crop rotation cycle. Sugarbeet plants are susceptible to *Rhizomania* ("root madness"), which turns the bulbous tap root into many small roots, making the crop economically unprocessable. Strict controls are enforced in European countries to prevent the spread, but it is already present in some areas. It is also susceptible to the beet leaf curl virus, which causes crinkling and stunting of the leaves.

Continual research looks for varieties with resistance, as well as increased sugar yield. Sugarbeet breeding research in the United States is most prominently conducted at

various USDA Agricultural Research Stations, including one in Fort Collins, Colorado, headed by Linda Hanson and Leonard Panella; one in Fargo, North Dakota, headed by John Wieland; and one at Michigan State University in East Lansing, Michigan, headed by J. Mitchell McGrath.

Other economically important members of the subfamily Chenopodioideae:

- Beetroot
- Chard
- *Mangelwurzel* or fodder beet.

2.6. Genetic modification

In the United States, genetically modified sugar beets, engineered for resistance to glyphosate, a herbicide marketed as Roundup, were developed by Monsanto as a genetically modified crop. In 2005, the US Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS) deregulated glyphosate-resistant sugar beets after it conducted an environmental assessment and determined glyphosate-resistant sugar beets were highly unlikely to become a plant pest. Sugar from glyphosate-resistant sugar beets has been approved for human and animal consumption in multiple countries, but commercial production of biotech beets has been approved only in the United States and Canada. Studies have concluded the sugar from glyphosate-resistant sugar beets has the same nutritional value as sugar from conventional sugar beets. After deregulation in 2005, glyphosate-resistant sugar beets were extensively adopted in the United States. About 95% of sugar beet acres in the US were planted with glyphosate-resistant seed in 2011.

Weeds may be chemically controlled using glyphosate without harming the crop. After planting sugar beet seed, weeds emerge in fields and growers apply glyphosate to control them. Glyphosate is commonly used in field crops because it controls a broad spectrum of weed species and has a low toxicity (Stephen and Stephen, 2008). A study from the UK (May *et al.,* 2005) suggests yields of genetically modified beet were greater than conventional, while another from the North Dakota State University extension service found lower yields (Mike, 2009). The introduction of glyphosate-resistant sugar beets may contribute to the growing number of glyphosate-resistant weeds, so Monsanto has developed a program to encourage growers to use different herbicide modes of action to control their weeds.

In 2008, the Center for Food Safety, the Sierra Club, the Organic Seed Alliance and High Mowing Seeds filed a lawsuit against USDA-APHIS regarding their decision to deregulate glyphosate-resistant sugar beets in 2005. The organizations expressed concerns regarding glyphosate-resistant sugar beets' ability to potentially cross-pollinate with conventional sugar beets. U.S. District Judge Jeffrey S. White, US District Court for the Northern District of California, revoked the deregulation of glyphosate-resistant sugarbeets and declared it unlawful for growers to plant glyphosate-resistant sugar beets in the spring of 2011. Believing a sugar shortage would occur USDA-APHIS developed three options in the environmental assessment to address the concerns of environmentalists. In 2011, a federal appeals court for the Northern district of California in San Francisco overturned the ruling. In July 2012, after completing an environmental impact assessment and a plant pest risk assessment the USDA deregulated Monsanto's Roundup Ready sugarbeets.

2.7. Genome and packaging into chromosomes

The sugarbeet genome has been sequenced and two reference genome sequences have already been generated (Dohm *et al.,* 2013; Funk *et al.,* 2018).The genome size of the sugar beet is approximately 731 Megabases, and sugarbeet DNA is packaged in 18 metacentric chromosomes (2n=2x=18) (Paesold *et al.,* 2012). All sugarbeet centromeres are made up of a single satellite DNA family (Zakrzewski *et al.,* 2013) and centromere-specific LTR retrotransposons (Weber *et al.,* 2013). More than 60% of sugarbeets DNA is repetitive, mostly distributed in a dispersed way along the chromosomes (Weber *et al.,* 2010; Wollrab *et al.,* 2012; Heitkam *et al.,* 2009; Schwichtenberg *et al.,* 2016).

Crop wild beet populations (*B. vulgaris* ssp. *maritima*) have been sequenced as well, allowing for identification of the resistance gene *Rz2* in the wild progenitor (Capistrano *et al.,* 2017). *Rz2* confers resistance to rhizomania, commonly known as the sugarbeet root madness disease.

2.8. General Description

The sugarbeet (*B. vulgaris* L.) belongs to the Chenopodiaceae family. This family includes approximately 1400 species divided into 105 genera (Watson and Dallwitz, 1992). Members of this family are dicotyledonous and usually herbaceous in nature. Economically important species in this family include sugarbeet, fodder beet/mangolds, red table beet, Swiss chard/leaf beet (all *B. vulgaris*), and spinach (*Spinacia oleracea*).

Sugarbeet is normally a biennial species, however under certain conditions it can act as an annual (Smith, 1987). The sugarbeet plant develops a large succulent taproot in the first year and a seed stalk the second year. Typically sugarbeet root crops are planted in

the spring and harvested in the autumn of the same year. For seed production, however, an overwintering period of cold temperatures of 4 - 7°C (vernalization) is required for the root to bolt in the next growing season and for the reproductive stage to be initiated (Smith, 1987).

During the first growing season, the vegetative stage, the sugarbeet plant is described as having glabrous leaves that are ovate to cordate in shape and dark green in colour. The leaves form a rosette from an underground stem. A white, fleshy taproot develops, prominently swollen at the junction of the stem (Duke, 1983). During the second growing season, the reproductive stage, a flowering stalk elongates (bolts) from the root. This angular seed stalk forms an inflorescence and grows approximately 1.2-1.8 metres tall. A large petiolate leaf develops at the base of the stem with small leaves, further up the stem there are less petiolate leaves and finally sessile leaves developing. At the leaf axils, secondary shoots develop forming a series of indeterminate racemes (Forster *et al.*, 1997). These flowers are small, sessile and occur singly or in clusters. Sugarbeets produce a perfect flower consisting of a tricarpellate pistil surrounded by five stamens and a perianth of five narrow sepals. Petals are absent and each flower is subtended by a slender green bract (Smith, 1987).

The ovary forms a fruit which is embedded in the base of the perianth of the flower. Each fruit contains a single seed whose shape varies from round to kidney-shaped. The ovaries are enclosed by the common receptacle of the flower cluster (Duke, 1983). A monogerm seed is formed when a flower occurs singly. The multigerm beet seed is formed by an aggregation of two or more flowers (Cooke and Scott, 1993).

2.9. Use as a Crop Plant

There is no seed production of sugarbeets in Canada. Most sugarbeet seed imported into Canada is produced in Oregon, USA (Webster, 2001). Sugarbeet roots are processed into white sugar, pulp and molasses for food, feed or industrial applications and are rarely used as a raw commodity. A typical sugarbeet root consists of 75.9% water, 2.6% non-sugars, 18.0% sugar and 5.5% pulp. In the sugar fraction 83.1% is recovered as crystalline sucrose, 12.5% is recovered as molasses (Bichsel, 1987). Sugar is a multi-purpose carbohydrate that contributes significantly to the flavor, aroma, texture, color and body of a variety of foods. In addition to processing pure sugar, sugar factories also produce a by-product known as dried sugarbeet pulp. This pulp is used as feed for cattle and sheep, and is produced and shipped in pressed plain dried, molasses dried, and pelleted forms. Another important by-product is sugarbeet molasses, a viscous liquid containing about 48% saccharose, which cannot be economically crystallized. Sugarbeet molasses is used for production of yeast, chemicals, pharmaceuticals, as well as in the production of mixed cattle feeds.

Currently, sugarbeet is the major sugar crop grown in temperate regions of the world. In Canada, sugarbeets are grown in the provinces of Alberta and Ontario. In 1998, 42,000 acres were planted in Alberta and 6,500 acres were planted in Ontario. Acreage of sugarbeet in Canada was significantly higher in 1998 than in previous years suggesting that future acreage may be on the rise (OMAFRA, 1998). In 1997, 650 thousand tons of sugarbeet were produced in Canada worth over $43 million (Canadian Sugar Beet Producers Association, 1997). Sugarbeet production in Canada represents about 10 to 15 percent of total domestic sugar consumption (Canadian Federation of Agriculture, 1998).

2.10. The Centers of Origin of the Species

The centre of origin of beet (*Beta*) is believed to be the Middle East, near the Tigris and Euphrates Rivers. It is thought that wild beets spread west into the Mediterranean and north along the Atlantic sea coast. Geographic isolation of wild beets on the Canary Islands led to the creation of several distinct species (*B. patellaris, B. webbiana* and *B. procumbens*) that are largely annual. The dispersal of wild types north into the mountains of Turkey, Iran, and the Caucasus Mountains of Russia, also led to the establishment of the species *B. trigyna, B. lomatogona,* and *B. macrorhiza* . These species are somewhat perennial in growth habit. Finally, wild beet spread east through most of Eastern Asia. Cultivated sugarbeet is likely to have originated from wild maritime beet (*B. vulgaris* subsp. *maritima*) through breeding selection (Cooke and Scott, 1993).

Historically, beets have been used for both livestock and human consumption. The first recorded use of beets is from the Middle East. Records dating to the 12th century contain the earliest descriptions of sugarbeets as plants with swollen roots (Toxopeus, 1984). It was not until the late 18th century, that German scientists began to breed beets to increase the sugar content of their roots (American Sugar beet Growers Association, 1998). Original forms of sugarbeet were derived from white Silesian beet, which had been used as a fodder crop and contained only about 4% sugar. Repeated selection and breeding have raised the sugar content to its present level.

2.11. Brief outlook at breeding, seed production and agronomic practices for sugarbeet

Early breeding techniques for sugarbeet were developed by the USDA and include cytoplasmic male sterility, monogerm seeds and hybrid vigor (Panella, 1996). Today, all U.S. sugar beet cultivars are monogerm hybrids. The use of monogerm sugarbeet seed has greatly reduced the need to thin clusters of sugarbeet seedlings, a requirement when multigerm seed was planted (Smith, 1987). Private seed companies now dominate sugarbeet breeding concentrating on varieties which produce high sucrose concentrations, have disease and pest resistance as well as herbicide tolerance.

Cytoplasmic male sterility (CMS) allows the breeder to develop male-sterile or female parental lines. These lines are a key factor in the breeding of hybrid cultivars (Forster *et al.*, 1997). Commonly, a monogerm O-type (or maintainer) line will be hybridized with the monogerm male-sterile equivalent of another line to produce a monogerm male-sterile F_1. The F_1 then is used as the seed parent in crosses with diploid or tetraploid pollinator lines (Forster *et al.*, 1997).

Data indicates that there is an inverse relationship between the weight of sugarbeets produced per unit area and the percentage of sugar produced (Smith, 1987). Recurrent and reciprocal recurrent selection techniques have not changed this relationship (Hecker, 1978). Originally sugarbeet was a diploid with 18 chromosomes (2x). Commercial exploitation of polyploidy in sugarbeets began in Europe in the 1940s with the development of anisoploid varieties. Such varieties were actually mixtures including diploid, triploid and tetraploid individuals, and were produced by interpollination of diploid and tetraploid seed-parents (Forster *et al.*, 1997). The use of cytoplasmic sterility

in conjunction with polyploidy allowed the production of triploid varieties. Currently there are diploid, triploid, and anisoploid varieties available (Forster *et al.*, 1997). Higher ploidy levels have been produced experimentally but have had limited usefulness. In Canada, the diploid hybrid cultivars are the dominant cultivars in use.

For seed production in Europe, small vegetative plants known as stecklings are produced in the first season. The following season they are transplanted into the field where seed production will take place. In the United States, 90-95 % of seed production is through the direct seed method. Seed is planted in August, overwinters, and the seed is harvested in July of the following year. Typically seed production areas are planted with 2 rows of pollinator stecklings followed by 4-8 rows of CMS stecklings. After flowering and pollen dispersal, the pollinator plants are removed in order to optimize seed quality.

Sugarbeet is sensitive to cold temperatures and is killed by frost at temperatures below -5°C. Hence, in Canadian agricultural practice, sugarbeet is handled as an annual crop with the roots being harvested for sugar after 5-7 months of growth. Yields of roots range from 10 to 35 tons per acre where sucrose concentrations range from 12-20% or more. The sugar content in the root is affected by nitrogen availability. Nitrogen should be applied early, as an excess late in the season reduces sugar content. To optimize sucrose storage in the roots, plants should exhaust the available nitrogen supply 4-6 weeks prior to harvest.

Sugarbeet is a poor competitor with weeds, particularly early in the season. Weed control is critical from the cotyledon to 12 leaf stage of seedling growth. In fields where weeds are never controlled and consist of tall growing species such as *Chenopodium album* (lambsquarters), yield loss can be as great as 95% (Scott and Wilcockson, 1976).

This, however, is unlikely in a commercial situation and a typical yield reduction due to weeds is generally 6-10% when weed control is used.

2.12. The Reproductive Biology of *B. vulgaris*

Sugarbeet seed is only produced by biennial flowers during the second year although certain conditions during the first year may cause premature bolting.

Flowers reach anthesis about 5 to 6 weeks after the initiation of reproductive development. Anthesis continues for a period of several weeks. After dehiscence of the mature anthers the globular pollen is transmitted largely by wind and occasionally by insects. Sugar beet pollen is extremely sensitive to moisture, however, under dry conditions its viability is lost within 24 hours. The primary method of pollination is cross pollination due to the lack of synchrony between pollen release and receptiveness of the stigma. Since the pollen can be carried by the wind over long distances, breeding stock and commercial seed production fields must ensure the isolation of flowering sugarbeet plants. According to the Canadian Seed Growers Association (CSGA) regulations, pedigreed sugarbeet crops must be isolated by 400 meters from any plants that are a source of contamination through cross pollination.

Sugarbeet is strongly self-sterile setting few or no seeds under strict isolation. The underlying genetic mechanisms may be explained by two series of multiple sterility alleles (S_1 - S_n, Z_1 - Z_n) (Stander, 1995). The setting of some seeds after selfing, so-called pseudo-compatibility, is due to a break-down of the incompatibility-mechanism (Stander, 1995).

Pseudo-compatibility is pronounced in varying degrees in different genotypes and is highly influenced by environmental conditions, especially temperature (Stander, 1995). There is a self-fertility gene which, when introduced, can create plants which are self-fertile (Smith, 1987).

2.13. Cultivated *B. vulgaris* as a Volunteer Weed

The occurrence of *B. vulgaris* in Canada is limited to commercial production for harvest of roots in Southern Alberta and Southwestern Ontario. Low temperatures and long day lengths can occasionally cause sugar beet to bolt, and set seed in the first year. This seed has the potential to result in weeds in subsequent crops.

Weed beet are defined as undesirable beet species (within the *Beta* Section) occurring in managed areas. While not a management issue in North America, weed beet is one of the most significant weed problems in European sugar beet production. In Europe, weed beet can arise as a result of contaminating pollen from sexually compatible wild annual relatives, bolting beet plants, dormant seed, and groundkeepers. Groundkeepers are small roots left in the field after harvest, which will flower in the next season if not controlled.

Occasionally, volunteer sugarbeets occur in Canada but do not become established as persistent weeds. Canada's cold winter climate does not allow sugarbeet roots to survive and any plants produced by seed from bolters do not persist long in the environment. Both lack of annual relatives and colder temperatures in Canadian growing areas, minimize weed beet. In crop production systems, volunteer beets are removed with the production practices that are normally used for crops that succeed beets in rotation. Sugar

beet is easily controlled by most broadleaf herbicides, however in some instances, herbicides that are registered for use on sugarbeet can cause damage to the beet crop.

2.14. Summary of Ecology of *B. vulgaris*

B. vulgaris is not a primary colonizer in unmanaged ecosystems. Seedlings of this species do not compete successfully against plants of similar types for space. In Canada, beets do not survive outside of cultivation for significant periods of time due to cold sensitivity and poor competitiveness.

In crop production systems, volunteers do not compete well with crops used in rotation with sugarbeets. In addition, volunteer sugar beets are removed by the typical production practices for crops that are used in rotation with beets, and sugarbeets can be easily controlled using chemical and/or mechanical control methods.

B. vulgaris is not listed as a noxious weed in the Weed Seed Order (1986). It is not reported as a pest or weed in managed ecosystems in Canada, nor is it recorded as being invasive of natural ecosystems. In summary, there is no evidence that in Canada, *B. vulgaris* has weed or pest characteristics.

2.15. Inter-Species/Genus Hybridization

Important in considering the potential environmental impact following the unconfined release of genetically modified *B. vulgaris*, is an understanding of the possible development of hybrids through interspecific and intergeneric crosses with the crop and related species. The development of hybrids could result in the introgression of the novel

traits into related species resulting in: Artificial hybrids between sugarbeet and members of the section *Procumbentes* have been produced with great difficulty. The hybrids become necrotic and die at the seedling stage. Successful hybrids can be produced by grafting hybrids onto sugarbeet plants or by using fodder beets, mangolds, *B. vulgaris* ssp. *maritima* as bridge species. These hybrids are almost completely sterile and fertile plants produce little seed upon backcrossing with *B. vulgaris*. Pollen sterility in F_1 and BC_1 generations is the result of abnormal meiosis. Chromosome lagging, multiple spindles, bridges and ejected chromosome have been frequently observed causing lack of fertility or embryo abortion. The chromosomes of the species of section Procumbentes do not pair with those of section *Beta* (Van Geyt *et al.*, 1990). No hybrids between cultivated beets and *B. nana* of section *Nanae* have been reported.

In conclusion, within the Family Chenopodiaceae, all crosses between cultivated sugarbeet and species from sections other than *Beta*, are highly improbable.

2.16. Potential for introgression of genetic information from *B. vulgaris* into relatives

All evidence demonstrates that *B. vulgaris* only forms hybrids with specific members of the Chenopodiaceae within the *Beta* section (De Bock, 1986). Natural hybridizations between cultivated beet and some wild or weedy forms of section Beta can occur in areas where both are present. Of the wild relatives that can hybridize with sugarbeet,

only *B. vulgaris* ssp. *maritima* and *B. vulgaris* ssp. *macrocarpa* are present in North America. These isolated populations are limited to California and are not found near sugarbeet seed production areas in that state.

2.17. Potential Interactions of *Beta vulgaris* with Other Life Forms

2.17.1. Sugarbeet Juice

Beet sugar processing is an operation in which sugarbeets are the raw material and white sugar is the primary product, and the complete process takes place in the one factory operation.

Sugarbeet processing is a seasonal operation, usually operating in Europe and North America for 3 or 4 months during the period August to February; this is the harvesting period for beet. About 7.5 tons of sugarbeets are required to produce 1 tons of refined sugar, and the logistics and equipment to handle these large quantities of beets are quite complex. Even a medium-sized beet factory can process 7000 tons of beets a day.

The sugarbeets are transferred into the plant using a water flume system, where various devices remove most of the foreign materials such as weeds, straw, stones, and rocks. The final removal of foreign material and soil is carried out in beet washers.

2.17.2 Diffusion

The beets are passed through a slicer, which produces long, thin strips called cossettes. These are passed into a diffuser, where sugar is continuously extracted in a stream of water. A common type of diffuser is a vertical drum. In this type the cossettes are transported upwards by a scroll, while the water passes down the drum, leaching sugar out of the cossettes as it passes through them. The temperature used in the diffuser is

usually about 65 °C, and the pH is maintained at about 6.5. The juice from the diffuser is around 15% solids, and most of the sugar in the beets is extracted. Effort is made to keep the extraction level as high as possible, around 98%. The cossettes after sugar extraction are called pulp, and this is processed for animal feed.

2.17.3. Origin, Plant Breeding, and Cultivation

Sugarbeet has been grown for sugar (sucrose) production only since the late eighteenth century, when Achard in Europe identified the 'white Silesian beet' as a source of sugar, and Napoleon encouraged breeding and processing research, to provide a home-produced alternative to cane sugar, which required shipment from the West Indies.

Sugarbeet, grown from seed, is a biennial plant which accomplishes vegetative growth in its first year and seed production in the second. For sugar production it is harvested at the end of the first year of growth, after a frost-free (preferably) period of 5–6 months, in areas with annual rainfall of some 20 cm. Irrigation is used in some areas, e.g., north-western USA. Sugarbeets are often used in crop rotation, as their deep roots bring up nutrients from lower levels of soil, to become available for alternate crops, and because they cannot be planted in the same field more than once every 3–4 years without risk of attack by nematodes. Beets for seed are grown in nonsugar-producing areas, notably in Oregon, where most US and European companies operate joint-venture seed companies with the purpose of maximizing germplasm resources.

Seed is, and has been since the 1940s, all monogerm hybrid, which permits mechanical planting and harvesting. The selected monogerm, male-sterile, inbred line and the multigerm pollinator (chosen for other desirable characteristics) are initially multiplied separately; the former is planted in strips together with the fertile monogerm

complementary line. Foundation seed produced by the male-sterile inbred furnishes the seed parent for the hybrid variety, which again is grown in strips with foundation seed of the pollinator. Monogerm hybrid seed is harvested only from the male-sterile parent, while the pollinator is destroyed soon after flowering.

2.17.4. Increased Susceptibility

Sugarbeet plants in the field that were infected with BMYV had greatly increased susceptibility to *Alternaria* infection; BYV had no such effect. BMYV increased and BYV decreased susceptibility to another fungus, *Erisphye polygoni*. Plants infected with both viruses had about the same susceptibility as healthy plants. The precise extent of the interaction depended on the genetic constitution of the host plant and on the environmental conditions.

2.17.5. Sugarbeet pulp

Non-starch carbohydrate feeds, such as sugarbeet pulp (SBP) and soya hulls, are now commonly added to diets for athletic horses. The carbohydrate fraction of these feeds is devoid of starch but rich in non-starch polysaccharides (fiber). SBP contains major fractions of pectins, arabinans, and galactans that are extensively fermented in the hindgut. Up to 3.0 g SBP per kg bodyweight have been fed to adult horses without any adverse effects on overall nutrient utilization or performance. Replacing oats with plain SBP will reduce the glycemic and insulinemic responses to a meal. However, when oats were replaced by molassed SBP there was no appreciable change in glycemic response although the post-prandial increase in insulin was mitigated.

Replacing oats with SBP also mitigates the rate of muscle glycogenolysis and the increases in muscle and plasma lactate in Standardbred trotters performing a treadmill exercise test that simulated a race. Similarly, replacing oats with barley sugar resulted in a significant reduction in muscle glycogen utilization during intense exercise. Therefore, a reduction in dietary starch, with replacement by SBP or barley sugar, modifies the muscle glycogenolytic response to high-intensity exercise. The mechanism of this apparent glycogen-sparing effect when oat starch is replaced by barley sugar or SBP is not known. Potentially, an increase in sugar intake results in enhanced use of plasma glucose for energy with a concomitant decrease in energy transduction from muscle glycogen.

Sugarbeet (*Beta vulgaris* L.) is one of the main industrial crops in Greece and in many other European countries. Rhizomania, the most important virus disease of the crop, can lead to severe losses in tap root yield and sugar content. The main symptoms of the disease are abnormal proliferation of fine rootlets from the taproot and lateral roots, partial necrosis of these tissues, necrosis of the vascular tissue and stunting of the tap root. The causative agent of the disease is the fungus-transmitted virus beet necrotic yellow vein virus (BNYVV). The vector of the virus, the soilbome obligate intracellular fungus *Polymyxa betae* transmits the virus in a persistent fashion. It is difficult to control the disease using environmentally acceptable methods, since the virus can survive in the spores of the fungus several years and soil decontamination is effective only after treatment with methyl bromide. Thus, if the disease invades the field, the only alternative for the farmer is the use of resistant cultivars. Generation of resistant varieties using transgenic plant approaches offer an alternative. Several approaches have been developed for pathogen-derived transgenic resistance. Transgenic lines containing and

expressing the BNYVV coat protein mRNA have been produced, and were found to contain reduced levels of the virus, although the coat protein was not in detectable amounts. Expression of full length coat protein may have a higher risk because of possible recombination or transencapsidation events. Over-expression of viral sequences in a plant may finally lead to the specific suppression of the gene, in a phenomenon called RNA-mediated resistance. This reaction, which is believed to be the result of a general plant defence mechanism, can lead to virus resistant or even immune plants.

As part of a wider sugarbeet breeding program aiming to create new sugarbeet cultivars resistant to the major diseases of the crop, we present here the first series of experiments for generation of virus resistant plants. BNYVV is a furovirus whose genome consists of four to five plus-sense RNAs. The genes on RNA 1, and 2 encode functions essential for Replicationon and movement in the plant, whereas the genes on RNAs 3, 4, and 5 are implicated in symptom expression or host range and vector-mediated infection of sugarbeet.

We introduced the viral gene sequence 13 K under the control of the CaMV 35S promoter in sugarbeet plants. The viral gene 13 K, which is located on RNA 2 of the virus in an area known as the triple gene block (TGB) encodes for a membrane protein which has a major role in the transport of the virus. Regenerated transgenic plants were challenged with the virus and examined for resistance.

2.17.6. Sugar industry

The beet and cane sugar industries use evaporation to concentrate the dilute sugar steam, as extracted from the beet or cane, up to the final concentration prior to crystallization,

itself a form of evaporation. Such systems are typically multieffect tubular systems, incorporating vapor recompression.

The production of sugar syrups (glucose, maltose, fructose) also requires evaporation: the raw syrup (often a product of the acid, alkali, or enzymatic hydrolysis of starch) is typically generated at 20–30% total solids and will need concentration up to 70–80% final solids. The evaporator is almost always a falling-film unit, incorporating either thermal or mechanical vapor recompression. Unlike the byproducts of starch processing, sugar syrups show very low fouling factors on evaporation.

2.17.7. Sugarbeet Mills

Effluent from sugarbeet processing comprises surplus transport water and wash waters. The concentration of organic matter increases from the start of the beet harvesting campaign and reaches a plateau after 1–2 months. Excess transport water, stored in large ponds, may be slightly sugary, containing organic matter such as root hairs, and with a BOD increasing to 3000 mg l^{-1} or more by the end of a campaign. The total water requirement for processing a tons of beet is approximately 9–19 m^3, and concentrated effluents have BOD values 4000–5000 mg l^{-1}. Effluent volumes using water recirculation are estimated to be 1.2 m^3 per tons of beet, 2–3 kg COD per tons and 200–600 kg SS per tons. COD values are approximately 1.5 times the BOD value.

2.18. Insect Pest of Sugarbeet

A number of insects can attack the developing plant. Sugarbeet root maggot is a major pest in Alberta and can be reduced by applying a suitable soil applied insecticide. Other invertebrate pests include cutworms, wireworms, flea beetles, grasshoppers, sugarbeet

root aphid, beet webworm, beet leaf miner and sugarbeet cyst nematode. The primary control for sugarbeet cyst nematode and diseases affecting sugar beet is crop rotation, with sugarbeet grown no more frequently than every fourth year with a grain or hay crop in the rotation (Alberta Agriculture, Food and Rural Development, 1998).

2.18.1 Sugarbeet caterpillar

The tobacco caterpillar *S. litura*, is one of the most important insect pests of agricultural crops in the Asian tropics. It is widely distributed throughout tropical and temperate Asia, Australasia and the Pacific Islands (Feakin, 1973; Kranz *et al.,* 1977). Records of *S. litura* having limited distribution in (or being eradicated from) Germany, Russian Federation, Russian Far East, the UK and Reunion may in fact refer to *S. littoralis*. Both *S. litura* and *S. littoralis* are totally polyphagous (Brown and Dewhurst, 1975; Holloway, 1989) and therefore have huge potential to invade new areas and/or to adapt to new climatic and/or ecological situations. The *Spodoptera* group consists of closely related species with similar ecology that are difficult to identify to species level.

The host range of *S. litura* covers at least 120 species. Among the main crop species attacked by *S. litura* in the tropics are *Colocasia esculenta*, cotton, flax, groundnuts, jute, lucerne, maize, rice, soyabeans, tea, and tobacco, vegetables (aubergines, *Brassica*, *Capsicum*, cucurbit vegetables, *Phaseolus*, potatoes, sweet potatoes and species of *Vigna*). Other hosts include ornamentals, wild plants, weeds and shade trees (for example, *Leucaena leucocephala*, and the shade tree of cocoa plantations in Indonesia).

2.19. Biology and ecology *S. litura*

S. litura eggs are laid in clusters of several hundreds, usually on the upper surface of the leaves. Fecundity varies from 2000 to 2600 eggs, and ovipositor days vary from 6 to 8 days. The developmental thresholds and thermal requirements for different stages of *S. litura* are 64 day degrees above threshold 8°C, from ovipositor to egg hatch, the larval period required 303 degree days and the pupa stage 155 degree days above a 10°C threshold. The response of various stages of *S. litura* to temperatures under constant laboratory conditions was similar to that under field conditions. The upper development threshold temperature for all stages was 37°C, and 40°C was lethal (Rao *et al.,* 1989).Eggs take 2-3 days to hatch, the larvae disperse quickly from the egg batch in groundnut. Newly hatched larvae can be detected by the 'scratch marks' they make on the leaf surface. The older larvae are night feeders and are usually found in the soil around the base of the plant during the daytime. They can chew large areas of leaf and at high population densities cause complete defoliation. The larvae can migrate in large groups from one field to another. In lighter soils, the larvae while hiding in the soil during daytime can also cause damage to groundnut pods.The larvae go through six instars and the final instars weigh up to 800 mg. Individual larvae can consume around 4 g fresh weight of groundnut foliage. However, 80% of the total consumption is in the final instar.Pupation takes place in the soil close to the plants. The pupa period lasts about 7-10 days. After adult emergence, peak oviposition occurs on the second night. Females mate three or four times during their lifetime, while males mate up to 10 times.In Andhra Pradesh, India, *S. litura* completes 12 generations a year, each lasting slightly more than a month in winter and less than a month in the hot season *S. litura* is known to be attacked

by many natural enemies at various life stages. Altogether, about 131 species of natural enemies have been reported from different parts of the world.

2.19.1 Egg Parasitoids

Four species of trichogrammatids, one scelionid and one braconid which had been reported as egg parasitoids of *S. litura,* an unidentified *Chelonus* species and species of *Telenomus,* have also been reported as both egg and larval parasitoids. A total of 10 egg parasitoids have been reported from different parts of the host distribution. Among the trichogrammatids, *T. chilonis* from India (Joshi et al., 1979) and *T. dendrolimi* from China (Chiu and Chou, 1976) are the most common. These species are often reported from the eggs of several other hosts.

2.19.2 Larval Parasitoids

Generally, the larval stage of *S. litura* is more prone to parasitism. Larval parasitoids of *S. litura* attack young to mature larvae and a few also attack eggs and larvae, and larvae and prepupae. Fifty-eight parasitoid species have been reported to attack the larval stage of this species. Of these, 47% were braconids, 19% ichneumonids, 16% tachinids, 10% eulophids, 3% chalcids, and 2% scelionids, encrytids and muscids. In general, 84% were Hymenoptera, and 16% Diptera.

In India, 32 different species of parasitoids have been reported as larval parasitoids of *S. litura*. Among these, *Apanteles* and species of *Bracon* were the most commonly reported. Rai (1974) surveyed vegetable crops in the state of Karnataka and found that

10% of larval mortality was caused by *Chelonus formosanus*. Jayanth and Nagarkatti (1984) reported the emergence of up to 12 tachninid parasitoids (*Peribaea orbata*) from a single *S. litura* larva in Karnataka state, India.

A pest survey of natural enemies of *S. litura* in Andhra Pradesh, India, reported *Zele chlorophthalma* as a larval parasitoid. Sathe (1987) in a survey for natural enemies of *S. litura* in Maharashtra region of India reported *Campoletes chlorideae* and *Apanteles colemani*. During the same survey two new Braconid species (*Enicospilus* sp. and *Echthromorpha* sp.) were found responsible for the 5% parasitization of *S. litura*, while *A. colemani* and *A. prodeniae* parasitized up to 20% larvae.

2.19.3. Pupal Parasitoids

Relatively few pupal parasitoids have been reported from *S. litura*. Eight parasitoid species have been reported from the pupal stage of *S. litura*, one of which is a larval-pupal parasitoid (*Ichneumon* sp.) and one a prepupal parasitoid (species of *Chelonus*).

2.19.4. Predators

Altogether 36 predatory insects from 14 families and 12 species of spiders, representing six families were reported to feed on *S. litura* eggs, larvae and pupae in different parts of the world. Of the total predators reported to feed on S. litura, 50% of the insect predatory fauna and 83% of the spiders were from India.

2.19.5. Diseases of *S. litura*

Nosema carpocapsae was found to infect *S. litura* larvae in New Zealand (Malone and Wigley, 1980), India (Narayanan and Jayaraj, 1979), Japan (Watanabe, 1976) and China (Tsai *et al.*, 1978; Li and Wenn, 1987).

So far four fungi have been reported to infect *S. litura* and cause physiological disorders in larval growth and development: *Aspergillus flavus*, *Beauveria bassiana*, *Nomuraea rileyi* and *Metarhizium anisopliae*. Zaz and Kishwaha (1983) reported *B. bassiana* infecting *S. litura* in cauliflower crops in Rajasthan. Siddaramaiah et al. (1986) reported an incidence of larval infection with *M. anisopliae* in groundnut in Karnataka. The infection first appeared in the second fortnight of June, was highest in mid-August, and decreased by November.

Viral diseases of this species have been reported from China, Japan, India and New Zealand. Among the viruses, nuclear polyhedrosis viruses are the most common and potent. Narayanan (1985) from Karnataka, reported the occurrence of a granulosis virus in dead *S. litura* larvae. Eggs and all six larval instars were highly susceptible to the virus, the mortality was 100% in eggs and first to fifth-instar larvae and 50% in the last larval instar. The disease killed older larvae more rapidly than younger ones.

Four nematode species have been reported parasitizing *S. litura* in India and one of them has also been reported in Japan. Bhatnagar *et al*., (1985) found *S. litura* larvae parasitized by the mermithid nematodes *Ovomermis albicans*, *Hexamermis* sp. and *Pentatomermis* sp. They observed more nematode activity on alfisols than on vertisols. They also discussed the population dynamics and distribution of nematodes and the arthropod hosts. Kondo and Ishibashi (1984) explained the infectivity and propagation of entomogenous nematodes *Steinernema* sp. on *S. litura* from Japan.

2.19.6. Prevention and control

The green revolution in Asia brought with it an increased awareness of the potential of insecticides for increasing the sustainability of rice production. Unfortunately, the

involvement of farms in insecticide-related technologies did not proceed as fast as the rate of subsidy spread and the overspill of insecticide usage into the fields of legume growers and horticulturalists. Legume pests are increasing in economic importance throughout Asia due to the destruction of natural control systems, and the build-up of insecticide resistance following the 'spraymania' of many farmers. If this is to be counteracted, natural control needs to be given increased emphasis as a component of the IPM approach. *S. litura* populations in groundnut fields are increasing in number and intensity, especially in fields where insecticides have been applied (Rao and Shanower, 1988).

2.19.7.1. Chemical Control

In the past, the control of arthropods depended mostly on inexpensive and efficient insecticides. But in recent years populations of many pests including *S. litura* have developed resistance to many commercially available pesticides (Ramakrishnan *et al.,* 1984; Naeem *et al.,* 2014). Studies at ICRISAT between 1991 and 1996 revealed the occurrence of resistance to cypermethrin, fenvalerate and quinalphos, by 197-, 121-, 29- and 362-fold, respectively.The control of arthropod pests is therefore becoming increasingly difficult and it is vital that all biological alternatives to insecticides need to be given greater priority, both in research and application.

New insecticides have been tested to deal with resistant strains of this moth and some promising results are coming forward (Venkateswarlu e*t al.,* 2005). Neem oil microemulsion proved significantly superior to macroemulsion (Swaran *et al.,* 2006).

New molecules such as chlorantraniliprole, spinosad and emamectin benzoate have shown promising results against *S. litura* (Gadhiya *et al.,* 2014) but chlorantraniliprole

gave the highest cost: benefit ratio among pesticides tested by Patil *et al.,* (2014) on soyabeans. Chatterjee and Mondal (2012) tested a number of new chemicals and their application methods on different vegetable crops in India and South-East Asia against lepidopterous pests and found flubendiamide, spinosad and chlorfenapyr to be the most effective.Following studies on the sublethal effects of mathofenozide, Shahout *et. al.* (2011) concluded that the effects of methoxyfenozide with its sterilizing properties, if used strategically on *S. litura*, might induce changes in the population dynamics of this pest in vegetable crops and could be considered a potent insecticidal compound for controlling this pest.

Suganthy and Sakthivel (2013) studied different bio-pesticides against *S. litura* infesting fields of *Gloriosa superba* and showed that flavonoids could be used as an alternative to chemical pesticide in the gloriosa ecosystem and as a component in organic pest management.

Plant oils and insecticides mixtures (synthetic pyrethroids) gave a higher mortality rate on 8-day-old larvae of *S. litura* than the synthethic pyrethroids alone (Anju and Srivastava, 2012).

2.19.7.2. Biological Control

In the past the mass releases of egg and larval parasitoids for the control of *S. litura* in different crops in different geographical regions had achieved only partial success. Observations in ICRISAT groundnut fields revealed more leaves with defoliator damage in insecticide applied fields than unsprayed areas (Wightman et al., 1990). Similar observations were also made during farmers' field surveys in the post-rainy season in coastal Andhra Pradesh, India (Rao and Shanower, 1988). In view of the development of

insecticidal resistance and the destruction of the natural enemies, and the polyphagous nature of this species, there is a need to give more consideration to the role of natural enemies as a component of integrated approaches to managing *S. litura*.

2.19.7.2.1. Egg parasitoids

Mass releases of an indigenous egg-larval parasite *Chelonus heliopae* in 1971-73 in Anand, Gujarat, India, against *S. litura* in cauliflower proved ineffective in controlling the pest. During 1974, weekly release of *Telenomus remus*, an egg parasitoid, in a tobacco nursery did not result in any parasitism. However, five weekly releases of 50,000 parasites per 0.2 ha and two releases of 15,000 parasitoids per 0.2 ha in cauliflower resulted in 60% parasitism. *T. remus* was introduced to Western Samoa and was recorded by Braune (1982) as a common egg-larval parasitoid of *S. litura*, with parasitism averaging 54%. Complete parasitization was observed only in small egg masses (up to 150 eggs) and the percentage of parasitization decreased with an increase in size of egg mass. *T. remus* could oviposit only in host eggs on the surface of the host egg mass. Thus the effectiveness of *T. remus* was limited to the large compact egg masses of *S. litura*.

2.19.7.2.2. Larval parasitoids

Six parasitoid species, *Apanteles ruficrus*, *Cotesia marginiventris*, *Apanteles kazak*, *Campoletes chloridae*, *Hyposoter didymator* and *T. remus* were introduced to Western Australia from overseas in 1978-83 and released against *S. litura* and 11 other economically important pests. The highest level of parasitism by *A. ruficrus* (80% and above) was noticed in *Mythimna* sp.Wang *et al.* (2014) studied the relationship between the larval parasitoid *Meteorus pulchricornis* and the bacterium *Empedobacter brevis.* The

study suggested that the bacteria has a negative effect on *M. pulchricornis*, but the impact could be alleviated by using low bacteria concentration and extending the time between the application and wasp release in biological control practices.

2.19.7.2.3. Predators

The biology of *Canthoconidia furcellata* was studied in the laboratory with a view to using this predator in an integrated pest management programme for tobacco pests. Chu and Chu (1975) studied the effects of temperature on the growth of *C. furcellata* and found that 71,216 and 134 degree days were required for egg, nymph and adult stages, respectively. It was concluded that there are five to six generations per year of this predator in northern Taiwan. Nakasuji *et al*,. (1976) observed a predatory wasp, preferentially selecting fifth- and sixth-instar larvae over early instars. The wasps were more active and attacked more larvae in fields with high larval density than those with low larval density. However, the percentage of predation was lower in the field with highest density of *S. litura* larvae. Deng and Jim (1985) reported *Conocephalus* sp. as a new predator on egg masses of *S. litura* in Guanxi, China. This katydid was successfully reared on an artificial diet. Field releases of nymphs and adults of *Conocephalus* sp. were attempted for control of *Scirpophaga incertulus*.

2.19.7.2.4. Pathogens

Ansari *et al.*, (1987) reported *Serratia marcescens* from Karnataka, India, attacking larvae of the noctuids *Helicoverpa armigera* and *S. litura*. In laboratory tests, *S. litura* was found to be more susceptible to the bacterium than *H. armigera*. The bacterium was equally pathogenic when ingested through artificial diet or the natural

food plant, but pathogenicity by contact application to the body of larvae was poor. Zaz and Kushwaha (1983) found *Bacillus thuringiensis* to be an effective microbial insecticide against *S. litura* larvae in cauliflower fields in Rajasthan, India.The efficiency of *B. thuringiensis* was enhanced significantely though protoplast fusion with a strain of *Bacillus subtilis* (Kannan *et al.*, 2014).

Phadke and Rao (1978) from India, investigated the pathogenicity of a green muscardine fungus *Nomuraea rileyi*. Laboratory studies in India indicated that this fungus was harmless to eggs of an egg parasitoid, *Telenomus preditor*, on *Achaea janata* and recommended the combined use of the fungus and the egg parasitoid in biocontrol programmes against *A. janata*. This may also apply to *S. litura* management.

Laboratory studies were undertaken to evaluate the bioefficacy of *Beauveria bassiana* against third-instar larvae of *S. litura*. *B. bassiana* was identified, isolated and maintained from field-collected cadavers of lepidopteran larvae. Minimum mortality was observed in the control, i.e. 23.3%, and the percentage mortality increased as the number of spores increased (Gupta and Bhupendra , 2014).

Research was also carried out on entophytic fungi (*Khuskia oryzae* and *Cladosporium uredinicola*), which showed adverse effects on survival and fitness of the insects (Abhinay *et al.,* 2014).Krishnaiah *et al.,* (1985) conducted field trials with a nuclear polyhedrosis virus against *S. litura* damage in black gram (*Vigna mungo*) fields in Andhra Pradesh, India. Two sprays of virus suspension gave effective control similar to chemical insecticides tested.

Chari *et al.,* (1985) evaluated the effectiveness of integrated management of natural enemies and viral diseases to control *S. litura* on tobacco seedlings in Gujarat, India. They concluded that a combination of biological control agents, insect growth regulators,

antifeedants and a trap crop on all sides of the nursery was an ecologically sound procedure for the control of *S. litura*.

Different doses of *Splt* MNPV on final instars of *S. litura* showed dose-related mortality, but sublethal doses on subsequent generations needs to be considered in the design of baculovirus-based pest management (Mohammad and Umi, 2008).

2.20. Integrated Pest Management

In recent years, due to crop failures experienced despite the use of several combinations of chemicals, an integrated approach based on cultural and biocontrol with efficient monitoring using pheromones has been developed. The IPM technology that has been developed and implemented in irrigated groundnut where *S. litura* is endemic has the following components:

- Clean cultivation to expose *Spodoptera* pupae to natural enemies and weather-related factors
- Sunflower, taro (Zhou, 2009) and castor plants (that attract *Spodoptera*) to be sown as trap crops both around and within fields
- Pheromone traps to predict *Spodoptera* egg laying
- Mechanical collection of egg masses and larvae from trap plants on alternate days following the 'warning' from the pheromone traps
- Application of fungicide (chlorothalonil) at the appearance of the first leaf spot lesions, and again after 10 days
- An application of neem kernel extract during the early stages of crop growth if necessary

-*Pongamia glabra* oil treatment on tomato plants gave significant reductions on the populations of *S. litura* while no adverse effect againsts it natural enemies (Marimuthu, 2008)

- Application of nuclear polyhedrosis virus at 500 larval equivalents per hectare in the evening if needed.

Sahayaraj (2011) gives a summary of different types of plant extracts used by farmer on groundnuts and discusses their effiency.

2.21. Monitoring

Developments in pheromone technology have made it possible to monitor *S. litura* in the field, to improve on timing of plant protection measures within groundnut IPM programs. The identification of a male sex pheromone of *S. litura*, (ZE) 9, 11-tetradecadienyl acetate and (ZE) 9, 12-tetradecadienyl acetate by Youshima *et al.,* (1974) has enabled effective monitoring of this species for several years. The basic work regarding trap design, height, longevity of the septa, and the potential role of this technology in groundnut has been thoroughly studied at ICRISAT Center, Hyderabad, India over the past decade. These studies have clearly indicated the migratory behavior of the species in different areas. At present, pheromone technology has given high priority in monitoring for timing of plant protection measures within groundnut IPM programs. The studies on trap density in groundnut situations indicated no significant differences in moth catches when there were four or more traps per hectare. No decline was noticed in moth catch with increase in trap density. This indirectly suggests a limitation in utilizing the technology in mass trapping operations.

However, there have been some promising results in monitoring the population of moths on Chinese cabbage (Yang *et al.,* 2009); spraying times and costs of chemical pesticides against *S. litura* were significantly reduced by the adoption of sex pheromone trapping. Population projections based on life tables and stage-specific consumption rates can reveal the stage structure and damage potential of the pest population of the moths (Tuan *et al.,* 2014). This method could prove to be more reliable as the data obtained by pheromone traps. It is evident that these life tables have to be developed for each area where the moth occurs and one should take into account climate change and yearly temperature and rainfall patterns. It was already established that minimum temperature is the predominant factor that influences pheromone traps whereas wind velocity is predominant in light traps. The overall influence of all the weather factors was high in case of pheromone traps compared to light trap (Prasad *et al.,* 2009).

2.22. Host-Plant Resistance

The development of resistance to *S. litura* in suitable groundnut varieties has been regarded as a high priority for Asian groundnut farmers for a number of years. The results of experiments carried out in 1986 and 1987 indicated the possibility that ICGV 86031 had some resistance to *S. litura* combined with high yield in the post-rainy season. This hope was substantiated in further tests on the ICRISAT research farm and in farmers' fields in coastal Andhra Pradesh (southern India). In the limited trials that have been carried out, farmers had sufficient confidence to grow this variety without protecting it with insecticides. They were rewarded with higher yields and lower variable costs than neighboring farmers who grew locally acceptable verities but applied insecticides to kill

defoliators. PI 269116, PI 269118 and PI 262042 had resistance to *S. litura*, but none were outstanding.

Bioassays carried out with larvae as preliminaries to detect the mechanism of resistance (independent tests by Ranga Rao (ICRISAT) and Padgham (NRI)) revealed no antibiosis effect on second- to sixth-instar larvae when fed mature leaves of ICGV 86031. The main mechanism of resistance is currently thought to be tolerance, manifested as the enhanced ability of vegetative tissue to regrow following defoliation.

However, first-instar larvae suffered 56% mortality when fed on ICGV 86031 compared with 12% mortality when fed on susceptible ICG 221. Padgham also found that newly hatched larvae had a marked propensity to vacate the leaves of this variety in the first 2 hours of free life. This suggests that the resistance factor which influences the neonates is associated with the leaf surface, because their feeding activity is restricted to scraping the leaf surface. The antixenosis demonstrated by ICGV 86031 is likely to increase the first-instar mortality that is characteristic of r-strategist noctuids and will therefore contribute to the determination of the level of damage caused by the older larvae among which mortality is comparatively low.

Amin *et al.,* (2011) investigated the morphological and biochemical characteristics of three varieties of cotton and observed their effect on feeding and growth of *S. litura*. At least one variety was not suited for cotton growers. In a study of the interaction between the virus and the parasitoid, the use of an appropriate concentration has the potential to improve the efficiency of the biological control.

CHAPTER III

MATERIALS AND METHODS

Five experiments were conducted, of which one in the Laboratory of Entomology division of Bangladesh Sugarcrop Research Institute (BSRI) and four in the experimental field of Sher-Bangla Agricultural University (SAU) during November 2017 to May, 2021. Other details of the methodology are furnished under different head and sub-heading the below:

3.1 EXPERIMENT 1

Screening the tolerant tropical sugarbeet varieties against sugarbeet caterpillar, *Spodoptera litura*

A practical selection program for a tropical sugarbeet variety required that genotypes carry out satisfactorily in appropriate conditions. If variety selection can be done on resistance against sugarbeet caterpillar infestation then the agronomic characteristics and phenotypic performance need to be evaluated from the beginning. However, for a number of reasons this is not always be practical and selection must be performed in artificial systems. Such selection must be rational by field trials. The objectives are to identify the resistant or least preferred tropical sugarbeet varieties against sugarbeet caterpillar *S.litura* and to assess the level of infestation of sugarbeet leaves and beet caused by *S. litura.*

The following necessary points were considered during persuing the research.

3.1.1 Location and season of the experiment

The field experiments were conducted at Sher-e-Bangla Agricultural University farm, Sher-e-Bangla Nagar, Dhaka during November 2017 to May, 2018. The research field is situated in the middle part of Bangladesh and located at $23^0 74^/$N latitude and $90^0 35^/$E longitude with an elevation of 8.2 meter from sea level. The experimental site lies at AEZ-28 (Madhupur Tract Agro-ecological zone) of Bangladesh (FAO, 1988).

3.1.2 Climate of the experimental areas

The climate of the locality is sub-tropical. It has characterized by high temperature, high humidity, and heavy rainfall during kharif season (April to September) and low rainfall associated with moderately low temperature during Rabi season (October to March). There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; rainy monsoon season from June to October; and a cool, dry winter from October to March. In general, maximum summer temperatures range between 30°C and 38°C. May (36˚C) is the warmest month in most parts of the country. January (13˚C) is the coldest month, when the average temperature for most of the country is about 10°C. The temperature and relative humidity were also moderate and varied with the different seasons. The relative humidity was also relatively low and it was ranged from 50 to 65 on an average in Rabi season. The metrological data for crop growing season were collected from Dhaka Metrological Office, Agargaon.

3.1.3 Soil characteristics

The SAU farm belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles, Soil pH 6.5. The experimental area was flat having available irrigation and drainage system. The land was above flood level and sufficient sunshine was available during the experimental period.

3.1.4. Sugarbeet cultivars used

Seeds of commonly used twelve tropical sugarbeet varieties collected from Bangladesh Sugarcrop Research Institute (BSRI) were cultivated in the research field under the experiment that includes-

i. SV-35
ii. SV-887
iii. SV-889
iv. SV-891
v. SV-892
vi. SV-893
vii. SV-894
viii. PAC-60008
ix. Danicia
x. Seranaada
xi. BSRI Sugarbeet-1 (Shubhra)
xii. BSRI Sugarbeet-2 (Cauvery)

The pictorial views of different cultivars of sugarbeet were shown in plate 1.

(a) **(b)** **(c)** **(d)**

(e) **(f)** **(g)** **(h)**

(i) **(j)** **(k)** **(l)**

Plate 1. Tropical Sugarbeet genotypes *viz.*, (a) SV-35, (b) SV-887, (c) SV-889, (d) SV-891, (e) SV-892, (f) SV-893, g) SV-894, (h) PAC-60008, (i) Danicia, (j) Serenada, (k) BSRI Sugarbeet-1 (Shubhra) and (l) BSRI Sugarbeet-2 (Cauvery).

3.1.5. Experimental design and Layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications in the field of the Experimental Farm of SAU. The whole field (0.055 ha) was divided into three blocks consisted twelve (12) plots of equal size (3.0 m x 2.0 m) having two (2) m space in between the blocks and one (1.0) m in between the plots.Thus, the total number of plots were thirty six (36). Treatmets were assigned to each block as per design of the experiment (plate 2).

Plate 2. Experimental plot showing different tropical sugarbeet genotypes.

3.1.6. Seed sowing

The seeds were sown by ridge methods in the spacing of 50 cm. x 20 cm., where seed to seed and row to row distance were 50 cm. and 20 cm. respectively at SAU Experimental Farm on 20 November 2017. Number of line per plot was four (4) and number of seed per line was fourteen (14).

3.1.7. Intercultural operations

3.1.7.1. Irrigation

First irrigation was done two days after seed sowing. Second and third irrigation was done at one and two months aged of the plant. Stagnant water was effectively drained out at the time of over irrigation. Urea and MoP were top dressed in two splits after 2nd and 3rd irrigation.

3.1.7.2. Thinning

Two seeds are sown in each pit. After two weeks one healthy seedling were kept for the study and rest were thinned out.

3.1.7.3. Weeding

Weeding was done as and when necessary to break the soil crust and to keep the plots free from weeds. First weeding was done after 20 days of planting and the rest were carried out at an interval of 25 days to keep the plot free from weeds.

3.1.7.4. Earthing up

Earthing up was done in each row to provide more soil at the base of each plant. This was done 30 and 60 days after sowing before irrigation.

3.1.8. Data recorded

The data were collected after planting of one month aged seedlings and continued up to last harvest. Under the following parameters the data were collected such as-

- **Germination Percentage:** Germination percentage is an estimate of the viability of seeds. The equation to calculate germination percentage was

$$GP = \frac{\text{Seeds germinated}}{\text{Total seeds}} \times 100$$

The germination rate provides a measure at the time course of seed germination.

- **Number of leaves plant $^{-1}$:** Total number of leaves of each plant was counted including those were senesced as long as they could be identified.
- **Number of infested leaves plant $^{-1}$:** Total number of leaves of each plant was counted and the number of infested leaves was also counted. The numbers of infested leaves were subtracted from total leaves. So the number of fresh leaves was found as well as number of infested leaves caused by larvae of *Spodoptera litura*.
- **Length of leaf:** Length of randomly selected leaf from each plant was measured by measuring tape and then average length (cm) was calculated.
- **LAI (Leaf area index):** Leaf area index (LAI) is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area in broadleaf canopies.

$$\text{LAI} = \frac{\text{Area of leaf coverage per plant}}{\text{Area of soil covered per plant}}$$

A leaf area index (LAI) expresses the leaf area per unit ground or trunk surface area of a plant and is commonly used as an indicator of the growth rate of a plant.

- **Dry matter:** The dry matter or dry weight is a measurement of the mass of something when completely dried. The beets were properly dried in open sunlight for 3 days then again dried in oven at 70°C temperature for 72 hours to remove the moisture for having constant weight. The dry matter of plant material consists of all its constituents excluding water.
- **Number of bore:** The numbers of bore caused by the larvae were counted from individual sugerbeet.
- **Number of larvae:** Number of larvae was counted from sugerbeet leaves. Firstly, the leaves of plant were recorded from the plot of sugarbeet and the larvae were also

recorded from each leaves. Then average was made and counted the average number of larvae from each plot.

- **Weight of beet:** Individual beet of sugarbeet was weighted. The weight of beet was expressed as gram (g).
- **Beet diameter:** Sugerbeet plants were selected randomly and uprooted and beet diameter was measured by measuring tape. Diameter of the sampled beet was recorded from top, middle, and lower portion of the beet. Beet diameter was measured in cm.
- **Length of beet:** Beet length was measured at harvest by measuring tape from apical tip to lower tip of sugarbeet and beet length was measured in cm.
- **Yield:** Sugarbeet from each plot were harvested, leaves were removed and beets were separated then the final beet weight was determined and recorded, which was later converted into ton per hectare.
- **Brix percentage of beet:** Brix is the content of soluble solids of the first stage juice processed by plant assessed by refractometer test. A refractometer determines degrees Brix by measuring the refraction of light passing through a liquid sample. Liquids containing sugar are denser than water and cause greater refraction as light passes through. The instrument compares this to the refraction of light through water and provides a Brix value.
- **Determination of Sucrose (Pol) percentage of beet:** Percent Pol or percent sucrose is the only sucrose content in the juice measured by polarimeter. Pol percent juice was measured by using automatic polarimeter (Model AP-300, Atago Co., Ltd., Japan). The clear juice was filled in a 200 mm polarimeter tube. Care was taken not to present any air bubbles inside the tube after filling with clarified juice. The

polarimeter/saccharimeter was adjusted and focused distinctly as the position of the image was changed. Correct adjustment was found both halves of the field of view appear in equal brightness and the direct pol was obtained from the scale. The pol was corrected against brix from the correction table (Ref.: Schmitiz's Table for sucrose (pol) for use in Horne's Dry Lead method with undiluted solution).

3.1.9. Data analysis

Data recorded for growth, phonological, yield and yield contributing characters were compiled and tabulated in proper form for statistical analysis. The collected data were analyzed statistically by using the "Statistix 10" computer package. Least Significant Difference (LSD) technique at 5% level of significance was used to compare the mean differences among the treatments (Gomez and Gomez, 1984).

3.2 EXPERIMENT 2

Toxic effect of insecticides on life stages of *Spodoptera litura* under laboratory condition

Spodoptera litura is a major problem of the sugarbeet crop. To manage the infestation of *S. litura*, indoor residual spraying (IRS) represents one of the main tools in the basic strategy applied in the sugarbeet crop field. It is essential to understand the residual efficacy of insecticides on different surfaces to determine spray cycles, ensure their rational use, and prevent wastage. This study aimed to evaluate the different life stages of sugarbeet caterpillar *S. litura* against the promising insecticides under laboratory condition and to determine the effective dose of insecticides and mortality percentage of larvae at different time interval.

3.2.1. Location and season

The study was conducted in the laboratory of Entomology division of Bangladesh Sugarcrop Research Institute (BSRI), Iswardi, Pabna during 15th March, 2020 to 20th May, 2018 to observe the duration of different instars (life cycle), pre-adult mortality percentage and adult longevity of *S. litura*.

The detail methodology of the study has been presented under the following sub-headings:-

3.2.2. Materials

Sugarbeet caterpillar *S. litura* infested beets and leaves were collected from experimental field. Different insecticides like Sevin 85WP (carbaryl), Dursban 20EC (chloropyriphos), Nitro 505EC (cypermethrin+chloropyriphos), Imitaf 20SL (imidacloprid), Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) were used

in this experiment. Needle, forcep, cotton, sugar syrup, measuring scale, moist soil, plastic container as well as different petridish of different diameter were used to test the mortality of insect populations (plate 4).

Plate 3. Insecticidal treatments on 3rd instar larae of *Spodoptera litura* under laboratory condition.

3.2.3. Methodology

The infested leaves with egg mass were collected from experimental field for rearing up to adults and tested in laboratory against insecticides (Plate 5). The purity of *S. litura* population collected from experimental fields were maintained. Data on hatching time, larval period, pupl period and also measured the days of adult emergence were recorded. Fourty four (44) petridish were placed with ten (10) third instar larvae in each Petridis to check the effectiveness of insecticides on different life cycle of *S. litura* under laboratory condition and data were recorded. Five promising insecticides as mentioned later with

two different doses (recommended doses and more than 25% of recommended doses) were applied at same time with an untreated control petridish and data were recorded at 8 hrs, 16 hrs, and 24 hrs. The mortality against discriminating doses of chemical treatments was determined for particular instar of larva.

3.2.4. Design of experiment

The experiment was laid out in a Completely Randomized Design **(**CRD) with four (4) replications.

3.2.5. Treatments

Eleven different combinations of insecticides were applied at the same time at laboratory condition. The treatments were:

T_1= Spraying of Acicarb 85WP solution (carbaryl) @ 3.5 g / liter of water.

T_2=Spraying of Acicarb 85WP solution (carbaryl) @ 4.5 g / liter of water.

T_3=Spraying of Dursban 20EC solution (chloropyriphos) 1.5ml / liter of water.

T_4=Spraying of Dursban 20EC solution (chloropyriphos) @ 2 ml / liter of water.

T_5=Spraying of Nitro 505EC solution (cypermethrin + chloropyriphos) @ 1.5ml. / liter of water.

T_6=Spraying of Nitro 505EC solution @ 2.0 ml. / liter of water.

T_7= Spraying of Imitaf 20SL solution (imidacloprid) @ 2.0 ml / liter of water.

T_8= Spraying of Imitaf 20SL solution (imidacloprid) @ 2.5ml / liter of water.

T_9=Spraying of Virtako 40 WG solution (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.15 g / liter of water.

T_{10}=Spraying of Virtako 40 WG solution (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g / liter of water.

T_{11}=Untreated control.

3.2.6. Data recorded

The data were recorded on different parameters by following the formula under the meintioned below:

- **Mortality of larvae:** According to Abbott's formula:

$$\text{Corrected (\%) Mortality} = \frac{X - Y}{X} \times 100$$

Where, X = percentage survival in the untreated control and

Y = percentage survival in the treated sample.

- **Growth of larval instar:** The growth of larvae was determined the number of days was required for the development of larvae from egg to larval stage and days were counted in each instar of larvae and pupal stage also.
- **Weight of larval instar:** Individual larva was weighted. The weight was expressed as milligram (mg).
- **Days of adult emergence:** The growth of adult emergence was determined the number of days was required for the development of adult from pupa stage to adult.

Plate 4. Egg mass of *Spodoptera litura* on sugarbeet leaf in the field

Plate 5. Burst egg mass of *spodoptera litura* became blackish in color

Plate 6. One-day-old larvae of *Spodoptera litura* came out from the egg mass

Plate 7. Two-days-aged larvae of *Spodoptera litura*.

Plate 8. Three-days-aged larvae of *Spodoptera litura* on sugarbeet leaf in the field

Plate 9. Four-days-aged larvae of *Spodoptera litura* in the petridish

Plate 10. Five-days-old larvae of *Spodoptera litura* in the petridish

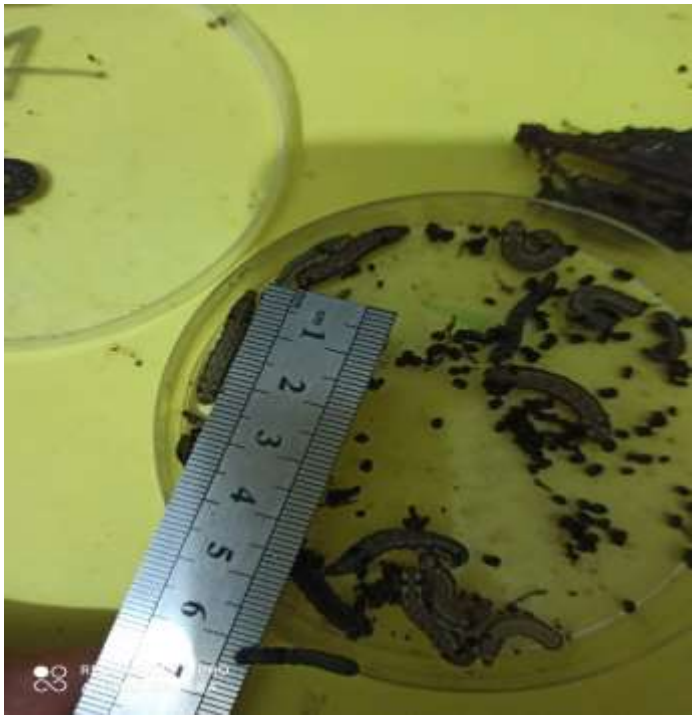


Plate 11. Measurement of five-days-old larvae of *Spodoptera litura* in the petridish

Plate 12. Six-days-aged larvae of *Spodoptera litura* in the petridish

Plate 13. Measurement of six-days-old larva of *Spodoptera litura*

Plate 14. Seven-days-old larvae of *Spodoptera litura* in the jar

Plate 15. Larvae of *Spodoptera litura* kept in the jar with moist soil for pupation

Plate 16. Larvae of *Spodoptera litura* transformed into pupa in the jar

Plate 17. Pupae of *Spodoptera litura*

Plate 18. Newly emerged adult moth in the jar

Plate 19. Adult of *Spodoptera litura*

Plate 20. Moth of *Spodoptera litura*

Plate 21. Moths of *Spodoptera litura* in the petridish

3.2.7. Data analysis

Data recorded for growth, growth contributing characters were compiled and tabulated in the proper form for statistical analysis. The collected data were analyzed statistically by using the "Statistix 10" computer package. Least Significant Difference (LSD) technique at 5% level of significance was used to compare the mean differences among the treatments (Gomez and Gomez, 1984).

3.3 EXPERIMENT-3:

Effect of insecticides for the management of *Spodoptera litura* in tropical sugarbeet

Broad-spectrum insecticides are effective against all insect pests. Using a targeted insecticide minimizes the risk to beneficial or non-target insects. Some insecticides work immediately to kill insects while others may need some time to be effective. The objectives are to identify the most effective insecticides for managing *Spdoptera litura* in tropical sugar beet and determine the effective dose of insecticides to control *Spdoptera litura.*

The details methodology of the study has been presented under the following sub-headings:-

3.3.1. Location and season

The study was conducted in the experimental field of Sher-e-Bangla Agricultural University (SAU), during November, 2018 to May, 2019.

3.3.2. Materials used

The sugarbeet variety BSRI Sugarbeet-2 (Cauvery) was cultivated in the field for combating *Spodoptera litura* caterpillar using different management practices. Eight insecticides like Acicarb 85WP (carbaryl), Dursban 20EC (chloropyriphos), Nitro 505EC (cypermethrin+chloropyriphos), Imitaf 20SL (imidacloprid), Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%), Nimbicidine (azadirachtin), Actara 25 WG (thiamethoxam) and Fighter 2.5EC (lamda cyhalothrin) were used in this experiment.

3.3.3. Design of experiment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications in the Experimental field of SAU. The whole field (0.042 ha) was divided into three blocks consisted of nine (9) plots of equal size (3.0 m x 2.0 m) having 2m space in between the blocks and 1m in between the plots.Thus, the total number of plots were twenty seven (27).

3.3.4. Treatments

The sugarbeet caterpillar *Spodoptera litura* were treated with eight popular insecticides such as-

T_1= Spraying of Acicarb 85WP (carbaryl) @ 4.5g / liter of water at 7 days interval.
T_2=Spraying of Dursban 20EC (chloropyriphos) @ 2.0 ml / liter of water at 7 days interval.
T_3=Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml / liter of water at 7 days interval.
T_4=Spraying of Imitaf 20SL (imidacloprid) @ 2.5 ml / liter of water at 7 days interval.
T_5=Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g / liter of water at 7 days interval.
T_6=Spraying of Nimbicidine (azadirachtin) @ 2ml / liter of water at 7 days interval.
T_7=Spraying of Actara 25WG (thiamethoxam) @ o.6 g / liter of water at 7 days interval.
T_8= Spraying of Fighter 2.5EC (lamd acyhalothrin) 2.0 ml / liter of water) at 7 days interval.
T_9=Untreated control.

3.3.5. Seed collection and seed sowing

The seeds of tropical Sugarbeet variety were collected from Bangladesh Sugarcrop Research Institute (BSRI). The seeds were sown by ridge methods in the spacing of 50 cm. x 20 cm. where plant to plant and row to row distance were 50 cm. and 20 cm.,

respectively. The necessary intercultural operations such as irrigation, weeding, earthing up, etc. were done properly.

3.3.6. Data collection

The data collection was started just prior to the application of the treatments at 7 days interval on different parameters such –

- **Number of plant:** Number of plant was counted from each unit plot of sugerbeet.
- **Number of infested plant:** Total number of plant was counted. All plants were counted including those that were senesced as long as they were identifiable.
- **Number of infested leaves per plant:** Total number of leaves of each plant was counted and the number of infested leaves was also counted. The number of infested leaves were subtract from number of total leaves. So the number of fresh leaves was found.
- **Number of larvae per 5 plants:** Number of larvae was counted from sugerbeet leaves. Firstly, the leaves were recorded from the plot of sugarbeet and the leaves of plant were also recorded. Then average was made and counted the average number of larvae from each of 5 plants. The number of larvae was recorded from the month of March, April and May and then made an average and calculated the percentage of efficacy over control.
- **Number of bore:** Number of bore was counted from individual sugerbeet.
- **Beet weight (g):** Five sugarbeet plants were selected randomly and uprooted from each unit plot.The leaves were detached from the beet then the sampled beet was weighted by digital balance at 150 DAS.

- **Beet length (cm):** Five sugarbeet plants were selected randomly and uprooted. The leaves were detached from the beet then beet length was measured by scale.
- **Beet diameter (cm):** Beet diameter was measured by slide calipers. Five sugarbeet plants were selected randomly and uprooted. Diameter of the sampled beet was recorded from top, middle and lower portion of the beet.
- **Brix percentage of beet:** Brix is the content of soluble solids of the first stage juice processed by plant assessed by refractometer test. A refractometer determines degrees Brix by measuring the refraction of light passing through a liquid sample. Liquids containing sugar are denser than water and cause greater refraction as light passes through. The instrument compares this to the refraction of light through water and provides a Brix value
- **Sucrose percentage of beet (Pol):** Percent Pol or percent sucrose is the only sucrose content in the juice measured by polarimeter. Pol percent juice was measured by using automatic polarimeter (Model AP-300, Atago Co., Ltd., Japan.)

3.3.7. Data analysis

Data recorded for growth, growth contributing characters were compiled and tabulated in proper form for statistical analysis. The collected data were analyzed statistically by using the "Statistix 10" computer package. Least Significant Difference (LSD) technique at 5% level of significance was used to compare the mean differences among the treatments (Gomez and Gomez, 1984).

3.4 EXPERIMENT-4:

Eefficacy of botanicals and non-chemical approaches against *Spodoptera litura* in tropical sugarbeet

Generally, bio-pesticides are made of living things, come from living things, or they are found in nature. They tend to pose fewer risks than conventional chemicals. Very small quantities can be effective and they tend to break down more quickly, which means less pollution. Botanical pesticides are efficacious in managing different insect pests as an inexpensive, easily biodegraded and have varied modes of action as well as their sources are easily available and have low toxicity to non-target organisms. So, the present study was considered to evaluate the efficiency of botanicals, pheromone traps and other non-chemical methods against *Spodoptera litura* for ensuring the eco-friendly management practices of *Spodoptera litura* in tropical sugarbeet.

3.4.1. Location and season

The study was conducted in the experimental field of Sher-e-Bangla Agricultural University (SAU), Dhaka during November, 2019 to May, 2020.

3.4.2. Materials used

The sugarbeet variety BSRI Sugarbeet-2 (Cauvery) were cultivated in the field for combating *Spodoptera litura* caterpillar using different management practices. Different bio-pesticides like Bio Neem plus® 1% EC (azadirachtin), Tracer 45SC (spinosad), Neem oil, NPV, Pheromone trap, Polythene for mulching and Hariken for light trap etc.

3.4.3. Design and layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications in the Experimental field of SAU. The whole field (0.042 ha) was divided into three blocks consisted of nine (9) plots of equal size (3.0 m x 2.0 m) having 2m space in between the blocks and 1m in between the plots.Thus, the total number of plots were twenty seven (27). Treatmets were assigned to each block as per design of the experiment.

3.4.4. Treatments

During the study period some selected non-chemical control options were used as treatments. So the eight management practices were applied in the study. There are as follows:-

T_1=Neem Oil @ 3ml/lit of water at 7 days interval.

T_2=Spraying of NPV @ 0.2 g/lit of water at 7 days interval.

T_3=Bio Neem plus® 1% EC (azadirachtin) @ 1ml /litof water at 7 days interval.

T_4=Tracer 45SC (spinosad) @ 0.5 ml /lit of water at 7 days interval.

T_5=Collection and destruction of egg mass and larvae (hand picking) at 7 days interval.

T_6=Light trap (one light trap per replication).

T_7=Polythene mulching trap per replication.

T_8=Pheromone trap (one pheromone trap per replication).

T_9=Control.

3.4.5. Seed collection and seed sowing

The seeds of tropical sugarbeet variety were collected from Bangladesh Sugarcrop Research Institute (BSRI). The seeds were sown by ridge methods in the spacing of 50 cm. x 20 cm. where plant to plant and row to row distance were 50 cm. and 20 cm., respectively at SAU Experimental farm on 18th November 2019.

3.4.6. Intercultural operations

When seedlings aged were Fifteen (15) days to keep one seedling in each hill for desired plant and rest were uprooting. The irrigation, weeding, tagging and other intercultural operations were done properly whenever necessary.

3.4.7. Treatment application

Various treatments as mentioned earlier were applied to the respective plot of the sugarbeet field. The first application of the treatments was done about two months after sowing seeds.

3.4.8. Data collection

The data were collected just before application of the treatments at 7 days interval on different parameters. There are given below:-

- **Number of infested plant:** Total number of plant was counted. All plants were counted including those that were senesced as long as they were identifiable.
- **Number of infested leaves per plant:** Total number of leaves of each plant was counted and the number of infested leaves was also counted. The number of infested leaves were subtract from number of total leaves. So the number of fresh leaves was found.

$$\text{No. of infested leaf /plant} = \frac{\text{Total no. of infested leaves of 5 plants}}{5}$$

- **Number of larvae per 5 plants:** Number of larvae was counted from sugerbeet leaves. Firstly, 5 sugarbeet plants were randomly selected and tagged from each plot of the field and then counted the total number of larvae from selected 5 plants leaves and data were recorded. The number of larvae was recorded from different date of the month of March, April and May and then made an average and calculated the percentage of efficacy over control.
- **Number of bore:** Number of bore was counted from individual sugerbeet.
- **Beet weight (g):** Five sugarbeet plants were selected randomly and uprooted from each unit plot.The leaves were detached from the beet then the sampled beet was weighted by digital balance at 150 DAS.
- **Beet length (cm):** Five sugarbeet plants were selected randomly and uprooted. The leaves were detached from the beet then beet length was measured by scale.
- **Beet diameter (cm):** Beet diameter was measured by slide calipers. Five sugarbeet plants were selected randomly and uprooted. Diameter of the sampled beet was recorded from top, middle and lower portion of the beet.
- **Brix percentage of beet:** Brix is the content of soluble solids of the first stage juice processed by plant assessed by refractometer test. A refractometer determines degrees Brix by measuring the refraction of light passing through a liquid sample. Liquids containing sugar are denser than water and cause greater refraction as light passes through. The instrument compares this to the refraction of light through water and provides a Brix value.
- **Sucrose percentage of beet (Pol):** Percent Pol or percent sucrose is the only sucrose content in the juice measured by polarimeter. Pol percent juice was measured by using automatic polarimeter (model AP-300, Atago Co., Ltd., Japan).

3.4.9. Data analysis

Data recorded for growth, growth contributing characters were compiled and tabulated in proper form for statistical analysis. The collected data were analyzed statistically by using the statistics 10 computer package. Least Significant Difference (LSD) technique at 5% level of significance was used to compare the mean differences among the treatments (Gomez and Gomez, 1984).

3.5 EXPERIMENT-5:

Development of IPM packages against S*pdoptera litura* for safe and hazards free tropical sugarbeet production of Bangladesh

Integrated Pest Management (IPM) is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. The objectives are to integrate in the best possible combinations of the tools identified from the previous experiment as effective, to develop effective IPM packages against S*pdoptera litura* in tropical sugar beet and to find out the safe and hazards free integrated packages for combating *S. litura.*

3.5.1. Location and season

The experiment was conducted in the experimental field of SAU, Dhaka during November, 2020 to May, 2021. The experimental field was located at 90°33´5´´ east longitude and 23° 77´4´´ north latitude at a height of 4 meter above the sea level. The land was medium high and well drained.

3.5.2. Materials used

The sugarbeet variety BSRI Sugarbeet-2 (Cauvery) was cultivated in the field for combating *Spodoptera litura* caterpillar using different management practices. Different insecticides like Nitro 505EC (cypermethrin+chloropyriphos) and Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) were used in this experiment. Moreover, Neem oil, NPV and Pheromone trap were also used.

3.5.3. Design and layout of experiment

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications in the Experimental field of the SAU Farm. The whole field (0.051 ha) was divided into three blocks consisted of eleven (11) plots of equal size (3.0 m x 2.0 m) having 2m space in between the blocks and 1m in between the plots.Thus, the total number of plots were thirty three (33). Treatmets were assigned to each block as per design of the experiment.

3.5.4. Seed collection and seed sowing

The seeds of tropical Sugarbeet variety were collected from Bangladesh Sugar Crops Research Institute (BSRI). The seeds were sown by ridge methods in the spacing of 50 cm. x 20 cm. where plant to plant and row to row distance were 50 cm and 20 cm respectively at SAU Experimental field on 30th November 2019. The necessary intercultural operation such as irrigation, weeding, earthing up etc. were done properly.

3.5.5. IPM Packages

IPM packages composed of combination of different treatments were designed. So, there were ten packages these are as follows:-

Pheromone Trap was installed in all treatments as common one.

T_1 = Hand Picking (Collection and destruction of egg masses and larvae) at 7 days interval

T_2 = Spraying of Neem oil @ 3ml /liter of water at 7 days interval

T_3 = Spraying of Nitro 505EC @ 2ml/liter of water at 7 days interval

T_4 = Spraying of Virtako 40WG @ 0.2 g /liter of water at 7 days interval

T_5 = Spraying of Neem oil @ 3ml/liter of water and Virtako 40 WG @ 0.2 g/lit of

water alternatively at 7 days interval

T_6 = Spraying of Neem oil @ 3ml/liter of water and Virtako 40 WG @ 0.2 g/lit of water alternatively at 7 days interval

T_7 = Spraying of NPV @ 0.2 g/liter of water at 7 days interval

T_8 = Hand Picking + Spraying of Neem oil @ 3ml/lit of water at 7 days interval

T_9 = Hand Picking + Spraying of Virtako 40WG @ 0.2 g/liter of water at 7 days interval

T_{10} = Hand Picking + Spraying of Nitro 505EC @ 2ml/liter of water at 7 days interval

T_{11} = Control

3.5.6. Data collection

The data collection was started just before application of the treatments at 7 days interval on different parameters.

- **Number of infested plant:** Total number of plant was counted. All plant were counted including those that were senesced as long as they were identifiable.
- **Number of infested leaves per plant:** Total number of leaves of each plant was counted and the number of infested leaves was also counted. The number of infested leaves were subtract from number of total leaves. So the number of fresh leaves was found.
- **Number of larvae per 5 plants:** Number of larvae was counted from sugerbeet leaves. Firstly, five (5) sugarbeet plants were randomly selected and tagged from each plot of the field and then counted the total number of larvae from the leaves of selected 5 plants and data were recorded. The number of larvae was recorded from different date of the month of March, April and May and then made an average and calculated the percentage of efficacy over control.

- **Number of bore:** Number of bore was counted from individual sugerbeet.
- **Beet weight (g):** Five sugarbeet plants were selected randomly and uprooted from each unit plot.The leaves were detached from the beet then the sampled beet was weighted by digital balance at 150 DAS.
- **Beet length (cm):** Five sugarbeet plants were selected randomly and uprooted. The leaves were detached from the beet then beet length was measured by scale.
- **Beet diameter (cm):** Beet diameter was measured by slide calipers. Five sugarbeet plants were selected randomly and uprooted. Diameter of the sampled beet was recorded from top, middle and lower portion of the beet.
- **Brix percentage of beet:** Brix percentage was measured by hand refractometer.
- **Sucrose percentage of beet (Pol):** Percent Pol or percent sucrose is the only sucrose content in the juice measured by polarimeter. Pol percent juice was measured by using automatic polarimeter (model AP-300, Atago Co., Ltd., Japan).

3.4.7. Data analysis

Data recorded for growth, growth contributing characters were compiled and tabulated in proper form for statistical analysis. The collected data were analyzed statistically by using the “Statistix 10” computer package. Least Significant Difference (LSD) technique at 5% level of significance was used to compare the mean differences among the treatments (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter includes the results and discussion covering the description of each experimental parameter, especially relevant for the particular experiment. The data have been presented in different tables and figures. To meet the objectives of the present study, five experiments were conducted of which one in the Laboratory of Entomology division of Bangladesh Sugarcrop Research Institute (BSRI) and four in the experimental field of Sher-e-Bangla Agricultural University (SAU) during November, 2017 to May, 2021. An attempt was taken for screening the tolerant source of tropical sugarbeet varieties against *Spodoptera litura* in first experiment. In second experiment, toxic effect of insecticides was observed on larval stages of *S. litura* under laboratory condition. In the third, fourth and fifth experiments, the effect of different insecticides for the management of *S. litura* in tropical sugarbeet, efficacy of botanicals and non-chemical approaches against *S. litura* in tropical sugarbeet and development of IPM packages against *S. litura* for safe and hazards free tropical sugarbeet production. The results have been discussed and all possible interpretations are given under the conducted experiments.

Experiment 1

Screening the tolerant tropical sugarbeet varieties against sugarbeet caterpillar *Spodoptera litura*

A practical selection program for a tropical sugarbeet variety was required whose genotypes carry out satisfactorily in appropriate conditions. For screening the resistant variety against *Spodoptera litura* the selection and variety trial process performed first. After that the agronomic characteristics and growth yield performances were evaluated. However, for a number of reasons this is not always practical and selection must be performed in artificial systems. Such selection must be rational by field trials. So the objective of the 1st experiment was to identify the resistant or least preferred tropical sugarbeet varieties against sugarbeet caterpillar *S. litura* and to assess the level of infestation of sugarbeet leaves and beet caused by *S. litura*. The result showed that the sugarbeet variety 'Cauvery' was the best suited variety to combat against *S. litura* infestation. The germination percentage was (94.87%) the highest compare to other varieties and the LAI and % DM also high. The final outcome was yield and its related parameter showed the positive relationship with yield and other yield contributing parameters. The second most favorable variety was Shubhra.

4.1. Effect of sugarbeet genotypes against sugarbeet caterpillar *Spodoptera litura*

4.1.1. Germination percentage

Germination percentage of studied sugarbeet varieties is presented in table 4.1.1. Germination occurred approximately 15 days after sowing seeds. The seeds were sown in slightly moist soil at a depth of three-quarters to 3.81 cm. Sugarbeet were adapted well to a various soil types, but the soil was well-drained and free of roots and large stones that can inhibit the roots' growth. Sugarbeet prefer a soil pH ranging 6.0 to 6.5.

Table 4.1.1. Estimated germination percentage, leaf area index (m^2), and percent dry matter of studied sugarbeet varieties

Variety	**Germination (%)**	**Leaf area index (m^2)**	**Dry matter (%)**
SV-35	85.90 de	6.87 c	9.73 b
SV-887	88.46 cde	7.23 bc	14.34 a
SV-889	89.74 bcd	7.57 bc	14.20 a
SV-891	89.10 bcde	7.35 bc	11.76 ab
SV-892	90.38 abcd	7.66 bc	10.61 b
SV-893	86.54 de	8.00 abc	12.54 ab
SV-894	91.67 abc	8.06 abc	10.42 ab
PAC-60008	84.62 e	6.77 c	11.14 ab
Danicia	87.18 cde	7.07 c	11.37 ab
Serenada	89.74 bcd	6.75 c	11.06 ab
Shubhra	93.59 ab	8.64 ab	12.07 ab
Cauvery	94.87 a	9.37 a	10.49 b
CV	**3.30**	**11.34**	**17.05**
LSD (0.05)	**2.59**	**1.46**	**3.36**

*Means in the same column followed by the different letters are significantly different at $p<0.05$

Statistically significant variation was observed for sugarbeet in terms of germination percentage. Germination percentage significantly affected yield of sugarbeet. The highest germination percentage (94.87%) was recorded at Cauvery variety which was statistically similar (93.59%) to Shubhra. The lowest germination percentage (84.62) was observed in PAC-60008. However, according to Islam *et al.,* (2014), the highest germination percentage was found in the variety PAC-60008 (93.14%) followed by Cauvery (92.85%) and the lowest was found in Shubhra (81.52%).

4.1.2. LAI (Leaf area index)

The leaf area index (LAI) is an important parameter in plant ecology and is presented in table 4.1.1. Because it tells how much foliage are there, it was a measure of the photosynthetic active area, and at the same time of the area subjected to transpiration. It was also the area which becomes in contact with air pollutants. Leaf area index (LAI) quantifies the amount of leaf material in a canopy. By definition, it was the ratio of one-sided leaf area per unit ground area. Leaf area per plant varied depending upon the growth stages, the minimum LAI (leaf area index) was recorded at 6.75 m^2 at Serenada variety while the maximum 9.37 m^2 at Cauvery variety. The second highest LAI was 8.64 m^2 at Shubhra variety. According to Islam *et al*., (2015) the highest (3.05) LAI was found in the variety SV892. At the earlier stages the leaf area of the treatments was inconsistent while at the later stages the effect of the treatments was found to be conspicuous. In this trial the variety had significant effect (at least at 5% level of significance) on leaf area index (Table 4.1.1).

4.1.3. DM (Dry matter)

Dry matter is the remaining part after all of the water is evaporated out of a feed, grain and fresh or dried forages. Fresh pasture has high water content and will have a lower percentage of dry matter than an equivalent weight of dryer feed, such as hay or grain. Dry matter is an indicator of the amount of nutrients that are available in a particular feed. Dry weight per plant increased progressively with the advancement of growth stages from after sowing up to maturity. The percent dry matter detected from the studied sugarbeet varieties is represented in table 4.1.1. The results showed the significant different among the varieties. The lowest % DM (percent of dry matter) was recorded 9.73 in SV-35 sugarbeet variety while the highest 14.34 in SV-887 Sugarbeet variety. The second highest % DM was 14.20 in SV-889 variety.

Table 4.1.2: Number of feeding bores and larvae per plant observed in twelve sugarbeet varieties

Variety	**Number of larvae/plant**	**Number of bore / beet**
SV-35	13.33 a	5.86 abc
SV-887	10.66 ab	4.80 abcd
SV-889	8.66 ab	3.60 bcd
SV-891	9.33 ab	3.80 bcd
SV-892	8.00 ab	3.86 bcd
SV-893	11.33 ab	6.13 ab
SV-894	8.66 ab	2.93 bcd
PAC-60008	14.66 a	7.73 a
Danicia	10.00 ab	5.13 abcd
Serenada	11.00 ab	5.66 abcd
Shubhra	7.33 ab	2.26 cd
Cauvery	2.00 b	2.20 d
CV	**66.62**	**47.49**
LSD (0.05)	**10.81**	**3.61**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

4.1.4. Number of *S. litura* larvae plant $^{-1}$

The larval stage contain five instars and the final instars weigh up to 800 mg. Individual larvae can consume around 4-8 g fresh weight of sugarbeet foliage. However, 80% of the total consumption is in the final instar. Numbers of larvae per plant varied depending upon the growth stages and indicate the plant resistance against specific insect (Table 4.1.2). The lowest number of larvae per plant were recorded 2.00 in Cauvery variety while the highest 14.66 in PAC-60008 variety. The second lowest number of larvae was 7.33 at Shubhra variety. In this trial, the variety had significant effect (at least at 5% level of significance) on number of larvae present per plant. The results were showing the effect of the individual variety of sugarbeet.

4.1.5. Number of bore beet $^{-1}$

Number of bore per beet varied depending upon the growth stages and indicates the plant resistance against specific insect. The lowest number of bore per beet were recorded 2.20 in Cauvery followed by 2.26 in Shubhra variety while the highest 7.73 in PAC-60008 variety. The number of larval bore per plant showed significant differences among the studied sugarbeet varieties.

Table 4.1.3. Yield contributing parameters of studied sugarbeet varieties

Variety	Beet weight (g)	Girth of beet (cm)	Length of beet (cm)	Yield (t/ha)
SV-35	711.67 f	24.67 e	26.33 e	76.88 e
SV-887	740.67 ef	26.67 cde	27.67 cd	84.44 abcd
SV-889	765.00 cd	27.33 cde	28.33 c	84.73 abcd
SV-891	753.00 de	27.00 cde	27.67 cd	86.20 abc
SV-892	798.00 bc	28.33 bcd	28.33 c	85.65 abc
SV-893	710.00 f	25.67 de	26.83 de	79.34 de
SV-894	808.00 b	28.67 abc	28.67 bc	87.15 ab
PAC-60008	693.67 g	27.67 cd	26.67 de	76.06 e
Danicia	731.67def	26.33 cde	27.00 de	83.17 bcd
Serenada	718.33 ef	26.00 cde	26.67 de	80.94 cde
Shubhra	813.33 b	30.67 ab	29.67 b	87.86 ab
Cauvery	851.67 a	31.33 a	31.67 a	89.96 a
CV	**3.13**	**5.96**	**2.78**	**4.29**
LSD (0.05)	**37.14**	**2.77**	**1.31**	**6.07**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

4.1.6. Beet weight

Beet weight can be determined the value of the sugarbeet variety at harvesting. The quality sugarbeet can produce more beet weight compare to other under favourable condition. The highest individual beet weight was recorded 851.67g in Cauvery variety followed by 813.33g in Shubhra, while the lowest was 693.67 g inPAC-60008 variety (Table 4.1.3). In this trial, the variety had significant effect (at least at 5% level of significance) on beet weight. According to Islam *et al.* (2014), the highest beet weight was found in the variety of Cauvery (995.70 g) and Shubhra (835.95g) which is little bit higher than the present study. This might be happened due to different soil and climatic conditions.

4.1.7. Beet girth

Beet girth can influence the quality of the sugarbeet variety at harvesting stage. From the table 4.1.3, it was found that the highest girth of beet was recorded 31.33 cm in Cauvery variety followed by Shubhra (31.00 cm), while the lowest 24.67 cm in SV-35 variety. The second highest girth of beet was 29.33 cm in SV-887 variety. The girth of sugarbeet revealed significant differences among the studied varieties. According to Islam *et al.,* (2014) the maximum beet breadth was found in variety Aranka (34.46cm).

4.1.8. Beet length

Beet length can determined the beet quality of the sugarbeet variety at harvesting stage. According to the table 4.1.3, the highest length of beet was recorded 31.67 cm in Cauvary variety, while the lowest was 26.33 cm in SV-35 variety. The second highest length of beet was 29.66 cm in Shubrha variety followed by SV-894 (28.66 cm). According to Islam *et al.,* (2014) also observed beet length and maximum was found in variety

Cauvery (31.24 cm) which is very close to our study. In this trial, the variety had significant differences among the studied varieties.

4.1.9. Yield

The yield of sugarbeet has continuously increased in the past decades. A key factor for increasing yield potential of the crop is breeding progress. It was related to a shift in assimilate partitioning in the plant toward more storage carbohydrates (sucrose), whereas structural carbohydrates (leaves, cell wall compounds) unintendedly declined. Yield can be determined by sum up the beet length, beet breadth and the weight of beet. The highest yield was recorded 89.96 t/ha in Cauvary variety, while the lowest 76.06 t/ha in PAC-60008 variety (Table 4.1.3). The second highest yield of beet was 87.86 t/ha in Shubrha variety followed by SV-894 (87.15 t/ha). According to Islam *et al.*, (2014), the maximum yield was found in variety Aranka (98.80 tha^{-1}) and lowest yield was found in variety Shubrha (59.90 t/ha). In this trial, the variety had significant effect (at least at 5% level of significance) on yield.

Table 4.1.4. Brix (%) and Pol (%) of studied sugarbeet varieties

Variety	**Brix (%)**	**Pol (%)**
SV-35	15.40 cd	11.39 b
SV-887	15.83 cd	11.80 ab
SV-889	17.73 ab	12.20 ab
SV-891	16.73 bc	12.09 ab
SV-892	17.76 ab	12.74 ab
SV-893	15.06 d	11.44 b
SV-894	17.80 ab	12.77 ab
PAC-60008	14.70 d	11.18 b
Danicia	15.80 cd	11.47 b
Serenada	15.50 cd	11.44 b
Shubhra	18.13 ab	13.36 a
Cauvery	18.23 a	13.45 a
CV	**5.11**	**8.29**
LSD (0.05)	**1.62**	**1.70**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

4.1.10. Brix Percentage

Percentage of Brix is the sugar content of an aqueous solution. One degree Brix is 1 gram of sucrose in 100 grams of solution and represents the strength of the solution as percentage by mass. The brix in twelve selected sugarbeet genotypes varied from 14.70 to 18.23 %. The highest brix percent was recorded 18.23 in Cauvary variety having no significant difference with Shubhra (18.13 %), SV-894 917.80 %), SV-892 917.76 5) and SV-889 (17.73 %). In contrast, the lowest brix percent was 14.70 in PAC-60008 and 15.06 in SV-893 having no significant difference with SV-35 (15.40 %), Serenada (15.50 %) and SV-887 (15.83 %) (Table 4.1.4). According to Islam *et al.,* (2014), the highest brix percentage was found in variety Shubhra, Cauvery and Aranka (18.48-18.87%) and lowest brix was found in variety HI-0044 (17.39%). In this trial, the variety had significant effect (at least at 5% level of significance) on brix

4.1.11. Pol Percentage

The highest Pol percentage was recorded 13.45 in Cauvary variety followed by 13.36% in Shubrha variety, while the lowest was 11.18% in PAC-60008 variety (Table 4.1.4). Islam *et al.,* (2014) tested the pol percentage and found maximum Pol in variety Aranka (10.08%). The significant differences were observed while tested the Pol percentages in different sugarbeet varieties.

The experiment indicates that the sugarbeet variety Cauvary was the best suited variety in this particular experiment. The germination percentage was high compare to other variety as well as the LAI and % DM also high. The variety Cauvary showed the positive relationship with yield and other yield regarding parameters. The second most favorable variety was Shubhra.

Experiment-2: Toxic effect of insecticides on larval stages of *Spodoptera litura* under laboratory condition

Spodoptera litura is a devastating pest of sugarbeet. In integrated management of *S. litura* infestation, indoor residual spraying (IRS) represents one of the main tools in the basic strategy applied in the sugarbeet crop field. It is essential to understand the residual efficacy of insecticides on different surfaces to determine spray cycles, ensure their rational use, and prevent wastage. The lowest days of adult emergence and weight of larvae were in T_6 (19±0.5) days and (17.8±0.8) mg, respectively. The highest effectiveness was found in T_6 (Spraying of Nitro 505EC solution @ 2.0ml/liter of water) and the highest mortality percentage at 3rd instar larvae.

The infested samples were collected from the field and reared the insects under laboratory condition. The eggs of sugarbeet caterpillar *Spodoptera litura* were 4-7 mm in diameter and female laid 200-300 eggs which are cream to golden brown in color. Egg hatched within 8-10 days. The larvae were 1.0 mm to 50.0 mm length with medium sized and dark green to brown color and formed pupal statge within 10-12 days. The pupae were 15-20 mm long and red to brown in color and became adult within 7-8 days (Fig 4.2.1). The upper development threshold temperature for all stages was 37°C, and 40°C was lethal (Ranga Rao *et al.,* 1989).

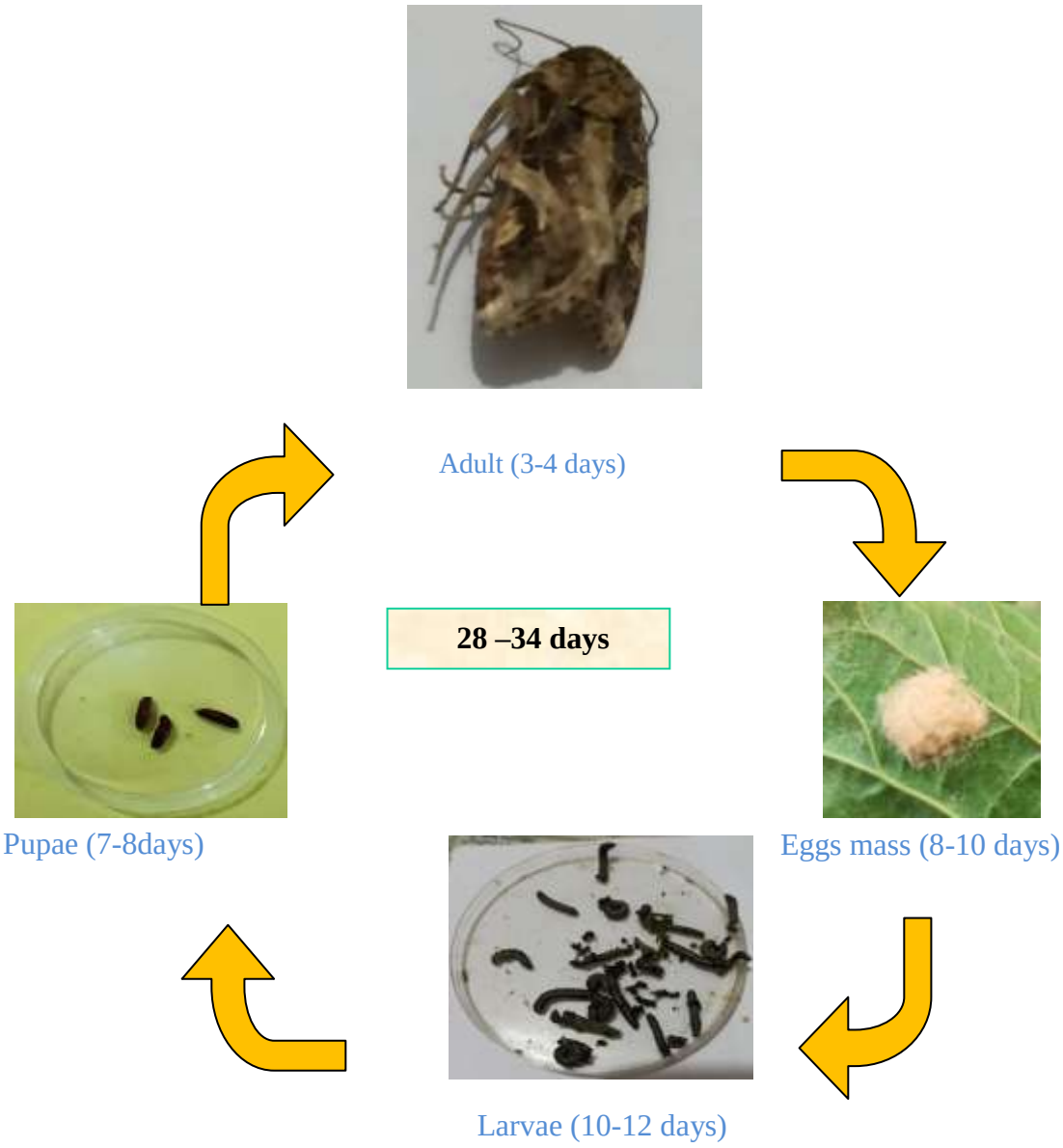


Figure 4.2.1: Life cycle of Sugarbeet caterpillar, *Spodoptera litura* with different life stages.

4.2.1. Mortality rate at different time interval

In the past, the control of arthropods depended mostly on inexpensive and efficient insecticides. But in recent years populations of many pests including *S. litura* have developed resistance to many commercially available pesticides (Ramakrishnan *et al.*, 1984; Naeem Abbas *et al.,* 2014). New insecticides have been tested to deal with resistant strains of this moth and some promising results are coming forward (Venkateswarlu *et al.,* 2005). Neem oil microemulsion proved significantly superior to macroemulsion (Swaran Dhingra *et al.,* 2006). New molecules such as chlorantraniliprole, spinosad and emamectin benzoate have shown promising results against *S. litura* (Gadhiya *et al.,* 2014) but chlorantraniliprole gave the highest cost: benefit ratio among pesticides tested by Patil *et al.,* (2014) on soyabeans. Effectiveness of different doses of insecticides was tested at three different schedules i.e. 8h, 16 h and 24 h respectively at 3rd larval stages under laboratory condition to evaluate effectiveness against larvae of the population of Sugarbeet caterpillar *Spodoptera litura.* The lowest (0 %) mortality percentage was observed after 8 h at laboratory condition in T_{11} (control) and T_1 (Spraying of Acicarb 85WP solution @ 3.5 g/liter of water) condition. The maximum (15%) mortality percentage of larvae were in T_{10} [Spraying of Virtako 40WG solution (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water] followed by (12.5%) in T_6 [Spraying of Nitro 505EC solution (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water]. However, the minimum (2.5%) mortality percentage of larvae in T_2 [Spraying of Acicarb 85WP solution @ 4.5 g/liter of water] (Fig. 4.2.2).

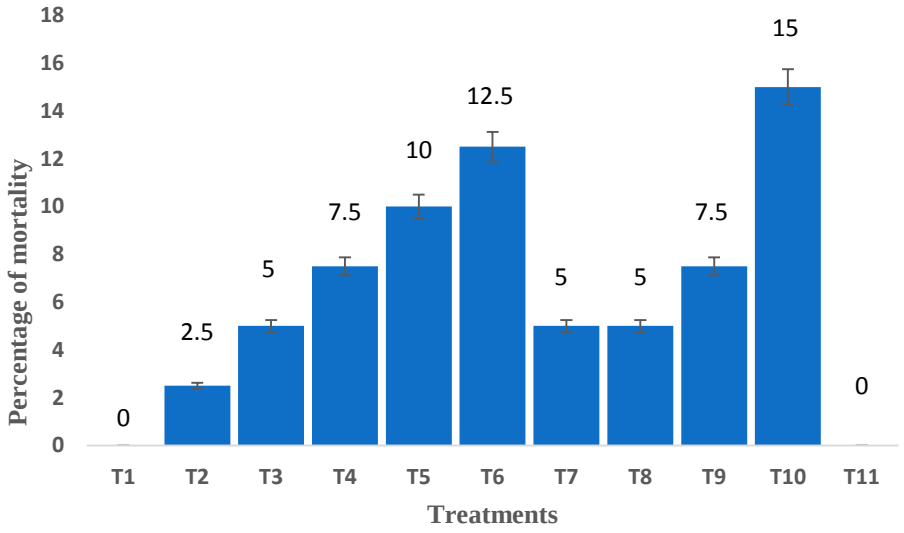


Figure: 4.2.2. Percentage of mortality rate while applied insecticidal treatment against sugarbeet caterpillar *Spodoptera litura* under laboratory condition after 8 h.

(T_1= Acicarb 85WP @ 3.5 g/liter of water, T_2= Acicarb 85WP @ 4.5 g/liter of water, T_3= Dursban 20EC 1.5 ml/liter of water, T_4= Dursban 20EC @ 2.0 ml/liter of water, T_5= Nitro 505EC @ 1.5 ml/liter of water, T_6= Nitro 505EC @ 2.0 ml/liter of water, T_7=Imitaf 20SL @ 2.0 ml/liter of water T_8= Imitaf 20SL @ 2.5 ml/liter of water, T_9= Virtako 40WG solution @ 0.15 g/liter of water, T_{10}= Virtako 40WG @ 0.2 g/lit of water and T_{11}=Untreated control.)

Moreover, the highest mortality percentage of larvae after 16 h at T_6 (Spraying of Nitro 505EC solution @ 2.0ml/liter of water) were 50.0 % and T_{10} (Spraying of Virtako 40WG solution @ 0.2 g/liter of water) were 50.0 %, while the lowest percentage of mortality was observed in T_{11} (Untreated control) 7.5% (Fig. 4.2.3). The number of larvae were died at control condition might be the environment were not favorable for the development of larvae. Plant oils and insecticides mixtures (synthetic pyrethroids) gave a higher mortality rate on 8-day-old larvae of *S. litura* than the synthethic pyrethroids alone (Anju and Srivastava, 2012). Rai (1974) surveyed vegetable crops in the state of Karnataka and found that 10% of larval mortality was caused by *Chelonus formosanus*. Jayanth and Nagarkatti (1984) reported the emergence of up to 12 tachninid parasitoids (*Peribaea orbata*) from a single *S. litura* larva in Karnataka state, India. Munir Ahmed *et al.*, (2005) studied effectiveness of some new chemistry insecticides against second instar larvae of leaf worm, *S. litura* at three different concentrations and reported that, emamectin benzoate 1.9 EC proved to be the best followed by lufenuron 5 EC, spinosad 45 SC and indoxacarb 15 SC, respectively. Stanley *et al* (2006) carried out studies on acute toxicity of emamectin benzoate (0.40 ppm) and spinosad (125 ppm) to *S. litura* for arriving at discriminating doses of resistance monitoring and reported that, the pest was highly susceptible to these insecticides and no resistance was detected.

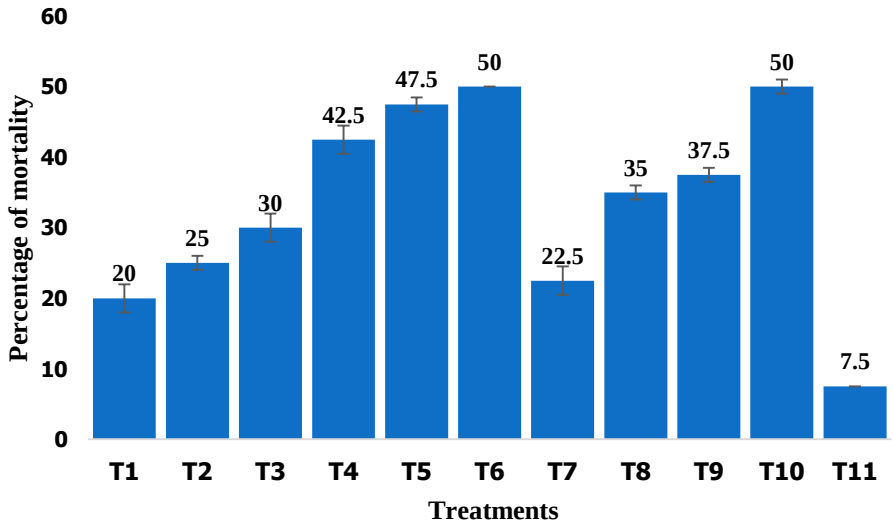


Figure: 4.2.3. Percentage of mortality rate while applied insecticidal treatment against sugarbeet caterpillar *Spodoptera litura* under laboratory condition after 16 h.

(T_1= Acicarb 85WP @ 3.5 g/liter of water, T_2= Acicarb 85WP @ 4.5 g/liter of water, T_3= Dursban 20EC 1.5 ml/liter of water, T_4= Dursban 20EC @ 2.0 ml/liter of water, T_5= Nitro 505EC @ 1.5 ml/liter of water, T_6= Nitro 505EC @ 2.0 ml/liter of water, T_7=Imitaf 20SL @ 2.0 ml/liter of water T_8= Imitaf 20SL @ 2.5 ml/liter of water, T_9= Virtako 40WG solution @ 0.15 g/liter of water, T_{10}= Virtako 40WG @ 0.2 g/lit of water and T_{11}=Untreated control.)

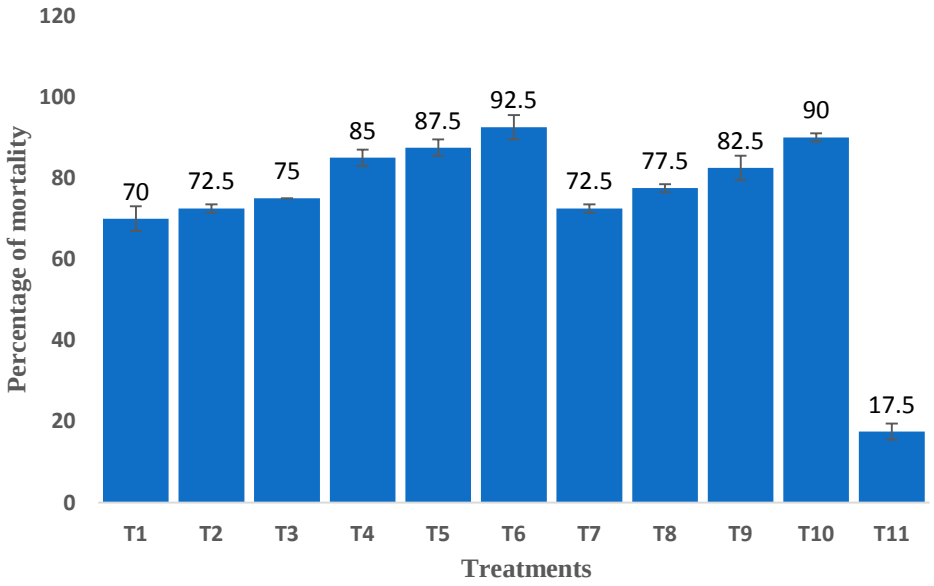


Figure: 4.2.4. Percentage of mortality rate while applied insecticidal treatment against sugarbeet caterpillar *Spodoptera litura* under laboratory condition after 24 h.

(T_1= Acicarb 85WP @ 3.5 g/liter of water, T_2= Acicarb 85WP @ 4.5 g/liter of water, T_3= Dursban 20EC 1.5 ml/liter of water, T_4= Dursban 20EC @ 2.0 ml/liter of water, T_5= Nitro 505EC @ 1.5 ml/liter of water, T_6= Nitro 505EC @ 2.0 ml/liter of water, T_7=Imitaf 20SL @ 2.0 ml/liter of water T_8= Imitaf 20SL @ 2.5 ml/liter of water, T_9= Virtako 40WG solution @ 0.15 g/liter of water, T_{10}= Virtako 40WG @ 0.2 g/lit of water and T_{11}=Untreated control.)

The highest mortality percentage of larvae were at T_6 (Spraying of Nitro 505 EC solution (cypermethrin + chloropyriphos) @ 2.0ml/lit of water) 92.50% followed by T_{10} (Spraying of Virtako 40 WG solution (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/lit of water) 90.00% (Fig. 4.2.4) at 24 h after application of treatment. However, the lowest mortality percent of larvae were at T_{11} (control) treatment 17.5%.

4.2.2. Percent increase over control

Mortality percent increase varied from zero percent to more than 400 percent compare with control treatment under laboratory condition (Fig. 4.2.5). But no treatment was less than 300 percent increase except control treatment. The highest mortality percent of larvae increase over control was in T_6 (Spraying of Nitro 505 EC solution (cypermethrin + chloropyriphos) @ 2.0ml/lit of water) 428.57% followed by T_{10} (Spraying of Virtako 40 WG solution (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/lit of water) 414.28%. However, the lowest mortality percent of larvae increase over control were at T_1 (Spraying of Acicarb 85 WP solution (carbaryl) @ 3.5 g/lit of water) 300% (Fig. 4.2.5). The highest effectiveness was found in T_6 (Spraying of Nitro 505 EC solution (cypermethrin + chloropyriphos) @ 2.0 ml/lit of water) might be both chemicals were active against 3rd instar larvae of sugarbeet caterpillar *Spodoptera litura* or single chemical could be active against larvae and other one accelerate it under that condition. Siddiquee *et al.*, (2007) was found the lowest (29.78) number of larval population due to the effects of spraying Nirto 505EC @ 4.5 L/ha at 15 days interval on sugerbeet field and percent of efficacy over control was the highest (84.48).

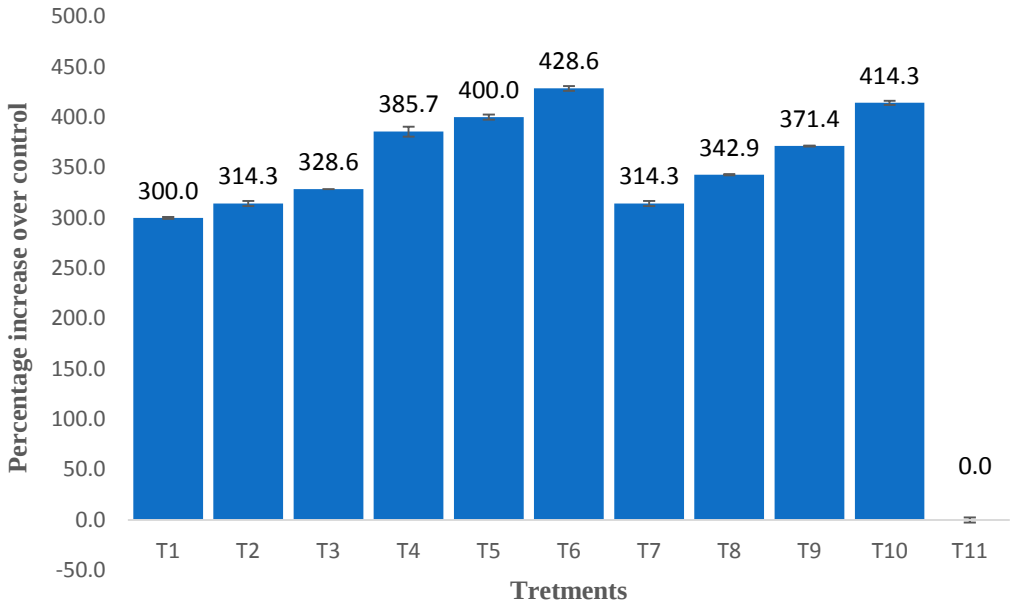


Figure: 4.2.5. Mortality rate of *Spodoptera litura* over control when applied insecticidal treatments after 24 h.

(T_1= Acicarb 85WP @ 3.5 g/liter of water, T_2= Acicarb 85WP @ 4.5 g/liter of water, T_3= Dursban 20EC 1.5 ml/liter of water, T_4= Dursban 20EC @ 2.0 ml/liter of water, T_5= Nitro 505EC @ 1.5 ml/liter of water, T_6= Nitro 505EC @ 2.0 ml/liter of water, T_7=Imitaf 20SL @ 2.0 ml/liter of water T_8= Imitaf 20SL @ 2.5 ml/liter of water, T_9= Virtako 40WG solution @ 0.15 g/liter of water, T_{10}= Virtako 40WG @ 0.2 g/lit of water and T_{11}=Untreated control.)

Table 4.2.1: Effect of different doses of insecticides on the mortality of 3rd instar larvae, growth, weight of the larvae and days of adult emergence of *Spodoptera litura*

Treatment	Mortality of 3rd instar larvae (%)	Growth of larval instar	weight of larvae (mg)	Days of adult emergence (day)
T_1	70.00	5th instar	22.7±0.8	26±0.2
T_2	72.50	5th instar	21.9±0.7	24±0.4
T_3	75.00	5th instar	21±0.6	23±0.5
T_4	85.00	5th instar	19.4±0.3	20±0.6
T_5	87.50	5th instar	18.2±0.5	20±0.3
T_6	92.50	5th instar	17.8±0.8	19±0.5
T_7	72.50	5th instar	22.3±0.6	26±0.8
T_8	77.50	5th instar	21±0.5	22±0.3
T_9	82.50	5th instar	20.3±0.4	22±0.6
T_{10}	90.00	5th instar	18.1±0.7	19±0.6
T_{11}	17.50	5th instar	23.1±0.8	27±0.7

(T_1= Acicarb 85WP @ 3.5 g/liter of water, T_2= Acicarb 85WP @ 4.5 g/liter of water, T_3= Dursban 20EC 1.5 ml/liter of water, T_4= Dursban 20EC @ 2.0 ml/liter of water, T_5= Nitro 505EC @ 1.5 ml/liter of water, T_6= Nitro 505EC @ 2.0 ml/liter of water, T_7=Imitaf 20SL @ 2.0 ml/liter of water T_8= Imitaf 20SL @ 2.5 ml/liter of water, T_9= Virtako 40WG solution @ 0.15 g/liter of water, T_{10}= Virtako 40WG @ 0.2 g/lit of water and T_{11}=Untreated control.)

4.2.3. Mortality rate of larvae, growth of larval instar and weight of the larvae

Mortality percentage varied from 17.5 percent to more than 90 percent compare with control treatment under laboratory condition (Table 4.2.1). After 24 h treatment the survived larvae were leavae for further development. The rest of the larvae completed 5^{th} larval instar and weight of the larvae were recorded.

The highest weight (mg) of larvae was inT_{11} (control) (23.1±0.8 mg) followed by T_1 (Spraying of Acicarb 85WP solution @ 3.5 g/liter of water) (22.7±0.8) (Table 4.2.1). However, the lowest weight of larvae was in T_6 (Spraying of Nitro 505EC solution @ 2.0 ml/liter of water) (17.8±0.8 mg). The highest effect was found in T_6 (Spraying of Nitro 505EC solution @ 2.0ml. / liter of water) and lowest weight 5^{th} instar larvae of *S. litura* might be control treatment provided less stress compared with other treatment. The rest of the larvae completed 5^{th} larval instar and days of adult emergence were recorded. The highest days of adult emergence was (27±0.7) in T_{11} (control) followed by (26±0.2) in T_1 (Spraying of Sevin 85WP @ 3.5 g/liter of water solution (Table 4.2.1). However, the lowest days of adult emergence was in T_6 [spraying of Nitro 505EC solution (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water] (19±0.5). The highest effect was found in T_6 [Spraying of Nitro 505 EC solution (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water). The T_6 treatment was observed the lowest days of adult emergence at 5^{th} instar larvae of *S. litura* because the stress might be accelerated the growth of larvae to adult.

4.2.3. Correlation between weight of larvae and mortality percentage of sugarbeet caterpillar *Spodoptera litura*

Under laboratory condition there was negative correlation (r= - 0.74) between weight of larvae and mortality percentage (Figure 4.2.6).The 'r' value indicated that the relationship was significant. The weight was the lowest when the mortality percentage was the highest. The weight of larvae increased with the decreasing mortality percentage.

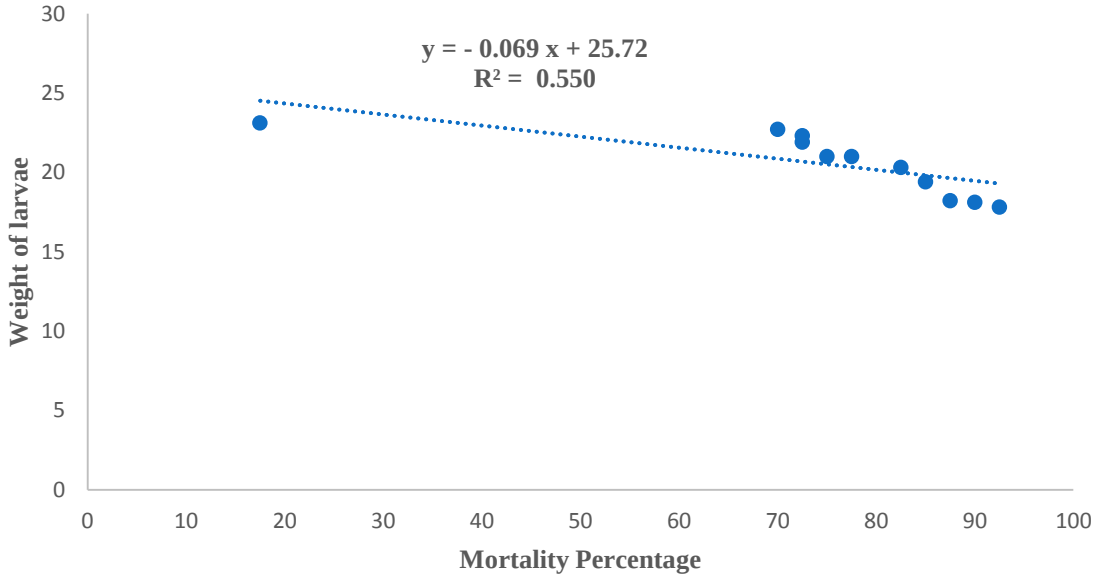


Figure: 4.2.6. Relationship between weight of larvae and mortality percentage of *Spodoptera litura* (r = - 0.74).

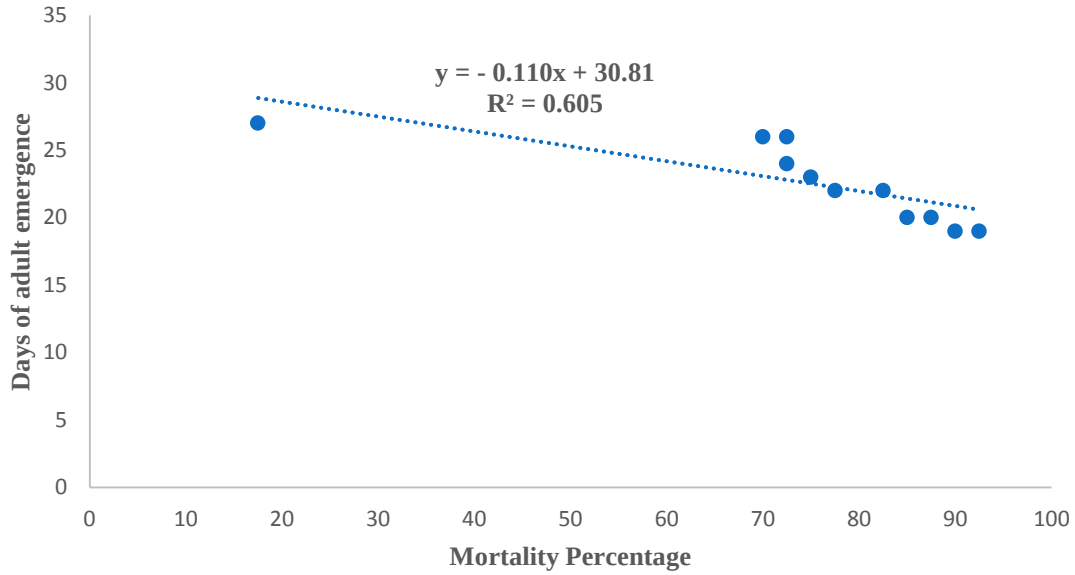


Figure: 4.2.7. Relationship between days of adult emergence and mortality percentage of *Spodoptera litura* (r = - 0.77).

Under laboratory condition there was negative correlation (r = - 0.77) between days of adult emergence and mortality percentage (Figure 4.2.7).The 'r' value indicated that the relationship was significant. The days of adult emergence was the lowest when the mortality percentage was the highest. The days of adult emergence increased with the decreasing mortality percentage.

Under laboratory condition there was positive correlation (r = 0.97) between date of adult emergence and weight of larvae (Fig. 4.2.7). The 'r'value indicates that the relationship was significant. The date of adult emergence was the lowest when the weight of larvae was also lowest. The weight of larvae increased with the increasing days of adult emergence.

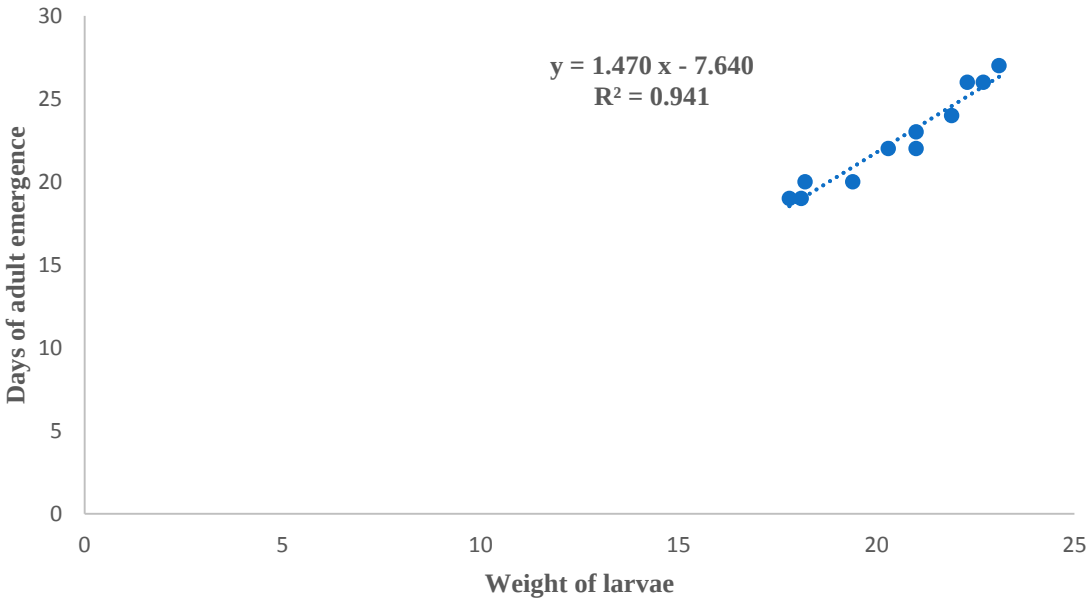


Figure: 4.2.8. Relationship between days of adult emergence and weight of larva of *Spodoptera litura* (r = 0.97).

The lowest days of adult emergence and weight of larvae were in T_6 [Spraying of Nitro 505EC solution (cypermethrin +chloropyriphos) @ 2.0 ml/liter of water] (19±0.5) and T_6 [Spraying of Nitro 505EC solution (cypermethrin + chloropyriphos) @ 2.0ml/liter of water] (17.8±0.8), respectively. The highest effect were found in T_6 (Spraying of Nitro 505EC solution @ 2.0ml/lit of water) and the highest mortality percentage at 3rd instar larvae of sugarbeet caterpillar *Spodoptera litura* might be both chemicals were active against 3rd instar larvae as it is assumed that single chemical could be active against larvae and other one accelerate it under that condition.

Experiment-3: Effect of insecticides for the management of *Spodoptera litura* in tropical sugarbeet

Broad-spectrum insecticides are effective against all insects, even the good ones. Other insecticides target certain insects. Using a specific insecticide minimizes the risk to beneficial or non-target insects. Some insecticides work immediately to kill insects while others may need some time to take effect. The objectives are to identify the most effective insecticides for managing *Spdoptera litura* in tropical sugarbeet and determine the effective dose of insecticides to control *S. litura.*The T_3 [(Spraying of Nitro 505 EC (cypermethrin + chloropyriphos) @ 2.0 ml/lit of water] and T_5 treatment [Spraying of Virtako 40 WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/lit. of water. at 7 days interval] was best suited and effective treatment and least resistant against insect pests compare to others.

4.3.1. Number of plants

Number of plants varied depending upon the growth stages and indicate the plant resistance against specific insect. The highest number of plant/plot was recorded 43.67 in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/liter of Water at 7 days interval) followed by 43.00 in T_5 (Virtako 40WG) while, the lowest was 39.67 in T_9 treatment (Control). The second lowest number of plant/plot was 41.67 in T_8 (Spraying Fighter 2.5EC (Lamdacyhalothrin) 2.0 ml/lit of water)). In this trial, the treatment had significant effect (at least at 5% level of significance) on number of plant (Fig. 4.3.1).

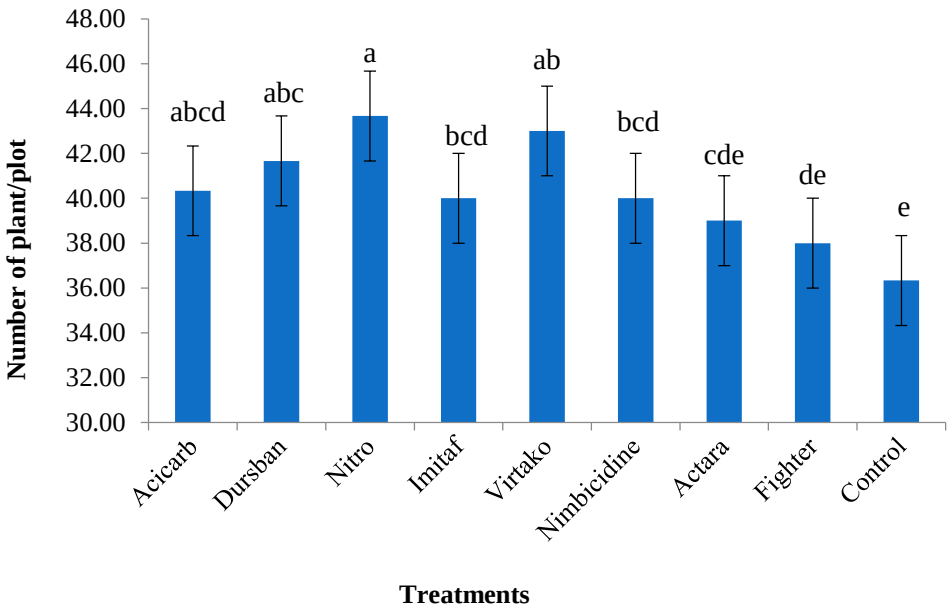


Figure: 4.3.1: Effect of insecticides for the management of *Spodoptera litura* in tropical sugarbeet.

* Bars with common letter are not significantly different ($p<0.05$).

T_1= Spraying of Acicarb 85WP (carbaryl) @ 4.5g/liter of water, T_2=Spraying of Dursban 20EC (chloropyriphos) @ 2.0 ml/liter of water, T_3=Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water, T_4=Spraying of Imitaf 20SL (imidacloprid) @ 2.5 ml/liter of water, T_5=Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water, T_6=Spraying of Nimbicidine (azadiractin) @ 2.0 ml/liter of water, T_7=Spraying of Actara 25WG (thiamethoxam) @ 0.6 g/liter of water, T_8= Spraying of Fighter 2.5EC (lamdacyhalothrin) 2.0 ml/liter of water) and T_9=Untreated control.

Table 4.3.1: Effect of insecticides on plant, leaf and beet of tropical sugarbeet

Treatments	No. of infested plant/plot	No. of infested leaf / 5 plant	No. of infested Beet / plot
T_1	9.66 ab	16.67 ab	12.33 b
T_2	8.00 ab	13.67 ab	5.00 e
T_3	7.00 b	11.67 b	4.67 e
T_4	9.00 ab	16.33 ab	10.67 b
T_5	7.67 ab	13.33 ab	5.33 de
T_6	8.33 ab	14.00 ab	6.33 de
T_7	8.67 ab	15.00 ab	7.00 cd
T_8	9.33 ab	15.67 ab	8.33 c
T_9	10.33 a	18.33 a	14.33 a
CV	**21.41**	**21.75**	**12.58**
LSD (0.05)	**3.21**	**5.63**	**1.79**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

T_1= Spraying of Acicarb 85WP (carbaryl) @ 4.5g/liter of water, T_2=Spraying of Dursban 20EC (chloropyriphos) @ 2.0 ml/liter of water, T_3=Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water, T_4=Spraying of Imitaf 20SL (imidacloprid) @ 2.5 ml/liter of water, T_5=Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water, T_6=Spraying of Nimbicidine (azadiractin) @ 2.0 ml/liter of water, T_7=Spraying of Actara 25WG (thiamethoxam) @ 0.6 g/liter of water, T_8= Spraying of Fighter 2.5EC (lamdacyhalothrin) 2.0 ml/liter of water) and T_9=Untreated control.

4.3.2. Number of infested plants

Number of infested plants varied depending upon the growth stages and indicate the plant resistance against specific insect. The lowest number of infested plant were recorded 7.00 in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/lit of Water at 7 days interval) while the highest 10.33 in T_9 treatment (Control). The second lowest number of plant was 7.67 at T_5 (Spraying of Virtako 40WG @ 0.2 g/lit. of water at 7 days interval) treatment. So, the number infested plants per plot showed the significant differences among the studied insecticides.

4.3.3. Effects of insecticides on leaf infestation

Infestations, particularly leaf infestation, are an important constraint to profitable production. The lowest number of infested leaves was recorded 11.67 in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/lit of Water at 7 days interval) while the highest 18.33 at T_9 treatment (Control). The second lowest number of leaves was 13.33 at T_5 (Spraying of Virtako 40WG @ 0.2 g/lit. of water at 7 days interval) treatment. In this trial, the treatment had significant effect (at least at 5% level of significance) on the number of infested leaves per plant (Table 4.3.1). Shahout *et. al.,* (2011) concluded that the effects of methoxy-fenzoide on *S. litura* might induce changes in the population dynamics of this pest in vegetable crops and could be considered a potent insecticidal compound for controlling this pest.

4.3.4. Effect of insecticides on the beet

The lowest number of infested beet was recorded 4.67 in T_3 treatment [Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of Water at 7 days interval] while the highest 14.33 at T_9 treatment (Control). The second lowest number of infested beet was 5.33 in T_5 [Virtako 40 WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water at 7 days interval] treatment.

Table 4.3.2: Effect of insecticides on the larval population of *Spodoptera litura* in various months

Treatments	Larval population (5 plants/plot)			Pool data	Percent efficacy over control
	March, 2019	April, 2019	May, 2019		
T_1	4.20 b	4.80bc	3.33 b	4.11 b	56.58
T_2	1.20 e	3.80 de	1.33 f	2.11 de	77.71
T_3	1.20 e	2.00 f	1.40ef	1.53 e	83.80
T_4	3.00 cd	5.40 b	3.00bc	3.80 bc	59.86
T_5	1.60 e	3.00 e	1.50ef	2.03 de	78.52
T_6	1.60 e	3.60 de	2.00 de	2.40 de	74.65
T_7	2.40 d	4.00 cd	2.40 cd	2.93 cd	69.01
T_8	3.60bc	4.00 cd	2.60 cd	3.40 bc	64.08
T_9	9.80 a	9.20 a	9.40 a	9.47 a	0.00
CV	**12.82**	**10.90**	**12.73**	**16.30**	**-**
LSD (0.05)	**0.69**	**0.82**	**0.65**	**0.99**	**-**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

T_1= Spraying of Acicarb 85WP (carbaryl) @ 4.5g/liter of water, T_2=Spraying of Dursban 20EC (chloropyriphos) @ 2.0 ml/liter of water, T_3=Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water, T_4=Spraying of Imitaf 20SL (imidacloprid) @ 2.5 ml/liter of water, T_5=Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water, T_6=Spraying of Nimbicidine (azadiractin) @ 2.0 ml/liter of water, T_7=Spraying of Actara 25WG (thiamethoxam) @ 0.6 g/liter of water, T_8= Spraying of Fighter 2.5EC (lamdacyhalothrin) 2.0 ml/liter of water) and T_9=Untreated control.

4.3.5. Effect of insecticides on larval population

Numbers of larvae per 5 plants varied depending upon the growth stages and indicate the plant resistance against specific insect. From Table 4.3.2 Sugarbeet larval population was collected five plants from each plot. The three months data were recorded statistically significant among the treatments in every month data. The highest number of larvae was recorded in the April followed by May. The lowest number of larvae was observed in the March. From the pool data the lowest number of larvae per 5 plant were recorded 1.53 in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/liter of Water at 7 days interval) while the highest 9.47 in T_9 treatment (Control). The second lowest number of larvae was 2.03 in T_5 (Spraying of Virtako 40 WG @ 0.2 g/liter of water at 7 days interval) treatment. The percent efficacy over control ranging from 56.58 to 83.80%. The highest efficacy over contro (83.80%) was found in Nitro 505EC treating plot followed by (78.52%%) in Virtako 40WG whereas the lowest 56.58% was found in Acicarb 85WP treating plot.

Rahman *et, al.,* (2017) also observed the highest (88.61 %%) efficacy over control in Nitro 505EC followed by (87.98 %%) in Virtako 40WG. Siddiquee *et, al.,* (2017) was also found the highest (81.06 %%) percent efficacy over control in Nitro 505EC treating plot which was very close to our study. So, the treatment had significant effect (at least at 5% level of significance) on the number of larvae.

Table 4.3.3: Effect of insecticides on weight, length and girth of beet for the management of *Spodoptera litura* in tropical sugarbeet

Treatments	Beet weight (g)	Beet length (cm)	Beet Girth (cm)
T_1	708.33	24.33	31.33
T_2	746.33	24.88	32.88
T_3	761.00	24.89	33.00
T_4	712.33	25.11	31.11
T_5	750.67	25.55	33.33
T_6	728.67	25.44	33.33
T_7	724.67	25.55	32.89
T_8	720.67	25.33	32.55
T_9	693.67	23.66	31.55
CV	**7.91**	**5.83**	**5.38**
LSD (0.05)	**99.56**	**2.51**	**3.02**

T_1= Spraying of Acicarb 85WP (carbaryl) @ 4.5g/liter of water, T_2=Spraying of Dursban 20EC (chloropyriphos) @ 2.0 ml/liter of water, T_3=Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water, T_4=Spraying of Imitaf 20SL (imidacloprid) @ 2.5 ml/liter of water, T_5=Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water, T_6=Spraying of Nimbicidine (azadiractin) @ 2.0 ml/liter of water, T_7=Spraying of Actara 25WG (thiamethoxam) @ 0.6 g/liter of water, T_8= Spraying of Fighter 2.5EC (lamdacyhalothrin) 2.0 ml/liter of water) and T_9=Untreated control.

4.3.6. Effect of insecticides on beet weight

Beet weight can be determined by taking weight of the sugarbeet during harvesting. The quality sugarbeet can produce more beet compare to other under favorable condition. The highest weight of beet was recorded 761.00 g in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) while, the lowest was 693.67g in T_9 treatment (Control) (Table 4.4.3). The second highest weight of beet was 750.67g in T_5 [Spraying of Virtako 40 WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water at 7 days interval] treatment. In this trial, the treatment had significant effect (at least at 5% level of significance) on beet weight.

4.3.7. Effect of insecticides on beet Length

Beet length can be determined the beet quality of the sugarbeet variety at harvesting. The highest length of beet was recorded 25.55 cm in T_5 (Spraying of Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment while the lowest was 23.66 cm in T_9 treatment (Control). The second highest length of beet was 25.44 cm in T_6 treatment [Spraying of Nimbicidine (azadirachtin) @ 2.0 ml/liter of water at 7 days interval]. In this trial, the treatment had significant effect (at least at 5% level of significance) on beet length (Table 4.3.3).

4.3.8. Effect of insecticides on beet Girth

The highest girth of beet was observed 33.33 cm in T_5 (Spraying of Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment while, the lowest was 31.11 cm in T_4 treatment (Spraying of Imitaf 20SL @ 2.5 ml/liter of water at 7 days interval). The second highest girth of beet was 33.00 cm in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) (Table 4.3.3).

Table 4.3.4: Effect of insecticides on the percentage of Brix and Pol for the management of *Spodoptera litura* in tropical sugarbeet

Treatments	Brix (%)	Pol (%)
T_1	15.83 b	10.33 bc
T_2	16.83 ab	11.66 ab
T_3	17.33 a	12.33 a
T_4	16.16 ab	10.66 abc
T_5	17.00 ab	12.00 ab
T_6	16.66 ab	11.33 abc
T_7	16.50 ab	11.33 abc
T_8	16.33 ab	11.00 abc
T_9	13.43 c	9.66 c
CV	**4.67**	**9.44**
LSD (0.05)	**1.31**	**1.82**

*Means in the same column followed by the different letters are significantly different at $p<0.05$

T_1= Spraying of Acicarb 85WP (carbaryl) @ 4.5g/liter of water, T_2=Spraying of Dursban 20EC (chloropyriphos) @ 2.0 ml/liter of water, T_3=Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water, T_4=Spraying of Imitaf 20SL (imidacloprid) @ 2.5 ml/liter of water, T_5=Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water, T_6=Spraying of Nimbicidine (azadiractin) @ 2.0 ml/liter of water, T_7=Spraying of Actara 25WG (thiamethoxam) @ 0.6 g/liter of water, T_8= Spraying of Fighter 2.5EC (lamdacyhalothrin) 2.0 ml/liter of water) and T_9=Untreated control.

4.3.9. Effect of insecticides on Brix percentage

The highest percentage of brix was recorded 17.33 in T_3 treatment (Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) while the lowest was 13.43% in T_9 treatment (Control). The second highest percentage of brix was 17.00 in T_5 treatment (Virtako 40WG @ 0.2 g/liter of water at 7 days interval) (Table 4.4.4). In this trial, the treatment had significant effect (at least at 5% level of significance) on brix (Table 4.3.4).

4.3.10. Effect of insecticides on Pol percent

The highest Pol percentage was observed 12.33 in T_3 treatment (Spraying of Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) while, the lowest was 9.66 in T_9 treatment (Control). The second highest Pol percent was 12.00 in T_5 treatment (Spraying of Virtako 40WG @ 0.2 g/liter of water at 7 days interval). In this trial, the treatment had significant effect (at least at 5% level of significance) on Pol (Table 4.3.4). The results were showing the significant differences among the studied insecticides for the managemint of *Spodoptera litura* in tropical sugarbeet. The T_5 treatment Virtako 40WG (Thiamethoxam 20% + Chlorantraniliprole 20%) @ 0.2 g/liter of water at 7 days interval) was the best suited treatment as showing the highest Pol (12.00 %).

Experiment-4: Eefficacy of botanicals and non-chemical approaches against *Spodoptera litura* in tropical sugarbeet.

Generally, bio-pesticides are made of living things, come from living things, or they are found in nature. They tend to pose fewer risks than conventional chemicals. Very small quantities can be effective and they tend to break down more quickly, which means less pollution. Botanical pesticides are efficacious in managing different crop pests, inexpensive, easily biodegraded, have varied modes of action, their sources are easily available and have low toxicity to non-target organisms. So, the present study was considered to evaluate the efficiency of botanicals, pheromone traps and other non-chemical methods against *Spodoptera litura* and to find out the eco-friendly management practices in the filed conditions. The T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) was a best performed treatment in this study. The resistance against insects pest were less compare to other.

4.4. Efficacy of botanicals and non-chemical treatments

4.4.1. Number of infested plants plot $^{-1}$

Number of infested plants varied depending upon the growth stages and indicates the plant resistance against specific insect. The lowest number of infested plant were recorded 5.66 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) while the highest 19.33 in T_9 treatment (control). The second lowest number of infested plants was 7.33 in T_8 (pheromone trap) treatment. Under the present study, the treatment had significant effect (at least at 5% level of significance) on number of infested plant (Table 4.4.1).

Table 4.4.1: Effect of botanicals, bio-pesticides and non-chemical approaches on plant, leaf, beet and bore of tropical sugarbeet

Treatments	No. of infested plant per plot	No. of infested leaf per plant	No. of infested beet per plot	No. of bore per beet
T_1	5.66 g	5.33 de	11.00 h	4.60 g
T_2	8.33 f	6.00 d	13.66 g	5.60 ef
T_3	9.66 e	7.66 c	16.66 f	5.73 def
T_4	10.66 de	8.33 c	19.33 e	6.00 cde
T_5	11.00 d	6.33 d	21.33 d	6.60 bcd
T_6	15.66 b	10.66 b	27.66 b	7.20 b
T_7	13.00 c	8.66 c	24.00 c	6.73 bc
T_8	7.33 f	4.66 e	12.66 g	4.93 fg
T_9	19.33 a	12.60 a	30.33 a	9.53 a
CV	**6.20**	**8.71**	**4.75**	**8.37**
LSD (0.05)	**1.20**	**1.17**	**1.61**	**0.91**

*Means in the same column followed by the different letters are significantly different at $p<0.05$

T_1=Neem oil @ 3ml/liter of water at 7 days interval, T_2=Spraying of NPV @ 0.2 g/liter of water at 7 days interval, T_3=Bio-Neem plus 1% EC (azadirachtin) @ 1ml/liter of water at 7 days interval, T_4=Tracer 45SC (spinosad) @ 0.5 ml/liter of water at 7 days interval, T_5=Collection and destruction of egg mass and larvae (hand picking), T_6=Light trap, T_7=Polythene mulching trap, T_8=Pheromone trap and T_9=Control.

4.4.2. Effect of botanicals, bio-pesticides and non-chemical approaches on leaves

Infestation, particularly leaf infestation, is an important constraint to profitable production. The results were showing the effect of different effectiveness of botanicals and other non-chemical approaches against *Spodoptera litura* in field condition. Number of infested leaves per plant varied depending upon the growth stages the plant resistance against specific insect. The lowest number of infested leaves were recorded 4.66 in T_8 (pheromone trap) treatment, while the highest number of infested leaves was 12.60 in T_9 treatment (control). The second lowest numbers of leaves were 5.33 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) treatment (Table 4.3.1).

4.4.3. Effect of botanicals, bio-pesticides and non-chemical approaches on beet

The highest number of infested beet was observed 30.33 in T_9 treatment (control) (Table 4.3.1) while the lowest 11.00 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval). The second highest number of infested beet was 27.66 in T_6 (light trap) treatment. In this trial, the treatment had significant effect (at least at 5% level of significance) on the number of infested beet per plot.

4.4.4. Effect of botanicals, bio-pesticides and non-chemical approaches on bore of beet

The lowest number of bore per beet was recorded 4.60 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval), while the highest number of bore per beet 9.53 in T_9 treatment (control). The second lowest number of bore was 4.93 in T_8 (pheromone trap) treatment. In this trial, the treatment had significant effect (at least at 5% level of significance) on the number of bore per beet (Table 4.3.1).

Table 4.4.2: Effect of botanicals, bio-pesticides and non-chemical approaches against larval population of *Spodoptera litura* in tropical sugarbeet

Treatments	Larval population (5 plants/plot)			Pool data	% efficacy over control
	March, 2020	April, 2020	May, 2020		
T_1	1.00 d	2.00 g	1.75 e	1.58 e	84.34
T_2	2.00 c	3.33 ef	2.33 e	2.55 de	74.74
T_3	2.33 c	3.80 e	3.20 d	3.11 cd	69.24
T_4	2.00 c	4.80 d	3.20 d	3.33 cd	67.03
T_5	2.33 c	5.33 cd	4.00 c	3.88 bc	61.56
T_6	4.20 b	5.80 c	5.00 b	5.00 b	50.54
T_7	2.33 c	7.00 b	3.33 cd	4.22 bc	58.26
T_8	1.33 d	2.50 fg	2.00 e	1.94 e	80.78
T_9	9.33 a	10.8 a	10.20 a	10.11 a	0.00
CV	**12.82**	**11.19**	**11.78**	**16.76**	
LSD (0.05)	**0.65**	**0.96**	**0.78**	**1.15**	

*Means in the same column followed by the different letters are significantly different at $p<0.05$

T_1=Neem oil @ 3ml/liter of water at 7 days interval, T_2=Spraying of NPV @ 0.2 g/liter of water at 7 days interval, T_3=Bio-Neem plus 1% EC (azadirachtin) @ 1ml/liter of water at 7 days interval, T_4=Tracer 45SC (spinosad) @ 0.5 ml/liter of water at 7 days interval, T_5=Collection and destruction of egg mass and larvae (hand picking), T_6=Light trap, T_7=Polythene mulching trap, T_8=Pheromone trap and T_9=Control.

4.4.5. Effect of botanicals, bio-pesticides and non-chemical approaches on the number of larvae 5 plant $^{-1}$

The number of larvae were collected from three different months. Under the present study it was observed that the highest number of larvae were recorded in April followed by May. The lowest number of larvae were observed in March (Table 4.4.2). From the pool data, the lowest number of larvae per 5 plants were recorded 1.58 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) followed by 1.94 in T_8 treatment (pheromone trap), while the highest number of larvae was 10.11 inT_9 treatment (control). Siddiquee *et al.,* (2017) showed that almost fifty percentage of larvae were controlled through bio-agent. The highest percent of efficacy over control was 84.34 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) followed by 80.78 in T_8 (pheromone trap). In this trial, the treatment had significant effect (at least at 5% level of significance) on the number of larvae (Table 4.4.2). Suganthy and Sakthivel (2013) studied the efficacy of different bio-pesticides against *S. litura* infesting fields of *Gloriosa superba* and showed that flavonoids could be used as an alternative to chemical pesticide in the *Gloriosa* ecosystem and as a component in organic pest management.

4.4.6. Effect of botanicals, bio-pesticides and non-chemical approaches on beet weight

Beet weight can be determined the value of the sugarbeet variety at harvesting. The highest weight of beet was recorded 791.33 g in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) treatment while, the lowest was 690.33 g in T_9 treatment (control). The second highest beet weight of beet was 784.00 g in T_8 (pheromone trap) treatment. In this trial, the treatment had significant effect (at least at 5% level of significance) on beet weight (Table 4.4.3).

Table 4.4.3: Effect of the different treatments on yield contributing characters of tropical sugarbeet

Treatment	Weight of beet(g)	Length of beet (cm)	Girth of beet(cm)
T_1	791.33 a	26.66 a	39.55
T_2	779.67 ab	26.88 a	40.44
T_3	761.00 ab	27.89 a	39.44
T_4	752.00 ab	27.33 a	37.55
T_5	747.33 ab	26.44 ab	36.66
T_6	712.33 ab	25.33 ab	37.11
T_7	726.33 ab	25.77 ab	37.44
T_8	784.00 a	23.44 b	37.66
T_9	690.33 b	26.11 ab	38.11
CV	**15.88**	**7.15**	**9.09**
LSD (0.05)	**0.92**	**3.19**	**NS**

*Means in the same column followed by the different letters are significantly different at $p<0.05$

T_1=Neem oil @ 3ml/liter of water at 7 days interval, T_2=Spraying of NPV @ 0.2 g/liter of water at 7 days interval, T_3=Bio-Neem plus 1% EC (azadirachtin) @ 1ml/liter of water at 7 days interval, T_4=Tracer 45SC (spinosad) @ 0.5 ml/liter of water at 7 days interval, T_5=Collection and destruction of egg mass and larvae (hand picking), T_6=Light trap,T_7=Polythene mulching trap, T_8=Pheromone trap and T_9=Control.

4.4.7. Effect of botanicals, bio-pesticides and non-chemical approaches on beet length

Beet length can be determined the beet quality of the sugarbeet variety at harvesting. The quality sugarbeet can produce more beet compare to other under favorable condition. The highest length of beet recorded 27.89 cm in T_3 treatment (Bio Neem plus 1% EC @ 1ml/liter of water at 7 days interval) while the lowest 23.44 cm in T_8 treatment (pheromone trap). The second highest length of beet was 27.33 cm in T_4 treatment [Tracer 45SC (spinosad) @ 0.5 ml/liter of water at 7 days interval]. In this trial the treatment had significant effect (at least at 5% level of significance) on the beet length (Table 4.4.3).

4.4.8. Effect of botanicals, bio-pesticides and non-chemical approaches on beet girth

The highest girth of beet recorded 40.44 cm in T_2 treatment (NPV @ 0.2 g/liter of water at 7 days interval) treatment while, the lowest 36.66 cm in T_5 treatment (collection and destruction of egg mass and larvae by hand picking). The second highest girth of beet was 39.55 cm in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval). In this trial, the treatment had no significant effect (at least at 5% level of significance) on the beet girth (Table 4.4.3).

Table 4.4.4: Effects of botanicals, bio-pesticides and non-chemical approaches on brix (%) and pol (%) of sugarbeet

Treatment	Brix (%)	Pol (%)
T_1	17.61 a	12.62 a
T_2	17.17 ab	11.72 bc
T_3	16.89 ab	11.41 bc
T_4	16.72 b	11.23 cd
T_5	16.61 bc	11.20 cd
T_6	15.67 d	10.59 d
T_7	15.87 cd	11.13 cd
T_8	17.33 ab	11.99 ab
T_9	14.61 e	9.41 e
CV	**2.86**	**3.78**
LSD (0.05)	**0.81**	**0.73**

*Means in the same column followed by the different letters are significantly different at $p<0.05$

T_1=Neem oil @ 3ml/liter of water at 7 days interval, T_2=Spraying of NPV @ 0.2 g/liter of water at 7 days interval, T_3=Bio-Neem plus 1% EC (azadirachtin) @ 1ml/liter of water at 7 days interval, T_4=Tracer 45SC (spinosad) @ 0.5 ml/liter of water at 7 days interval, T_5=Collection and destruction of egg mass and larvae (hand picking), T_6=Light trap,T_7=Polythene mulching trap, T_8=Pheromone trap and T_9=Control.

4.3.9. Effect of botanicals, bio-pesticides and non-chemical approaches on Brix (%)

The highest brix percentage was recorded 17.61 in T_1 treatment (neem oil @ 3.0 ml/liter of water at 7 days interval) while, the lowest was (14.61 %) in T_9 treatment (control). The second highest brix was 17.38 % in T_8 treatment (pheromone trap) followed by T_2 and T_3 treatment (Table 4.3.4). In this trial, the treatment had significant effect (at least at 5% level of significance) on brix percentages.

4.3.10. Effect of botanicals, bio-pesticides and non-chemical approaches on Pol (%)

The highest Pol percentage was observed 12.62 percentage in T_1 treatment (neem oil @ 3.0 ml/liter of water at 7 days interval) while, the lowest was (9.41 %) in T_9 treatment (control). The second highest Pol was 11.99% in T_8 treatment (pheromone trap). In this trial, the treatment had significant effect (at least at 5% level of significance) on Pol percentages (Table 4.3.4).

The T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) was the best suited treatment under the experiment. The T_1 treatment was high value compared to other treatment in different parameter. The neem oil has some chemical which influence resistance against *Spodoptera litura* and gave highest brix and Pol percentage.

Experiment-5: Development of IPM packages against S*pdoptera litura* for safe and hazards free tropical sugarbeet production of Bangladesh

Integrated Pest Management (IPM) is an effective and eco-friendly approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. The objectives are to integrate the best possible combinations of the tools identified from the previous experiment as effective, develop effective IPM packages against *Spdoptera litura* in tropical sugarbeet and to find out the safe and hazards free integrated package for combating *S. litura.*The experimental field of SAU, Dhaka of Bangladesh during November' 2020 to May, 2021. As a result, the T_{10} treatment (pheromone trap + hand picking + spraying of Nitro 505EC @ 2ml/liter of water at 7 days interval) was a best suited treatment in the experiment. The percent efficacy over control of insect larvae was highest (78.43 %) compared to other.The T_{10} treatment was also high value Brix (19.50%), Pol (12.00 %) and yield as compared to other teratments.

4.5. Effect of IPM packages against the infestation of *S. litura*

4.5.1. Number of infested plants plot $^{-1}$

Numbers of infested plants varied depending upon the growth stages and indicate the plant resistance against specific insect. The lowest numbers of plant were recorded at 4.33 inT_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval) while the highest 9.00 in T_{11} treatment (control). The second lowest number of plant was 5.00 in T_9 (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment (Table 4.5.1).

Table 4.5.1: Effects of different integrated pest management components against plant and leaves of tropical sugarbeet

Treatments	No. of infested plant plot^{-1}	No. of infested leaves 5 plant^{-1}
T_1	8.00 ab	28.00 ab
T_2	6.66 bcd	25.33 abc
T_3	5.33 cde	23.00 bc
T_4	5.66 cde	23.33 bc
T_5	6.00 bcde	24.33 bc
T_6	6.33 bcde	25.00 abc
T_7	7.00 abcd	26.00 abc
T_8	7.33 abc	26.66 abc
T_9	5.00 de	22.00 bc
T_{10}	4.33 e	21.00 c
T_{11}	9.00 a	31.33 a
CV	**21.18**	**25.09**
LSD (0.05)	**2.31**	**6.92**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

T_1: Pheromone trap + Hand picking at 7 days interval, **T_2:** Pheromone trap + Neem oil @ 3ml/liter of water at 7 days interval, **T_3:** Pheromone trap + Nitro 505EC @ 2 ml/liter of water at 7 days interval, **T_4:** Pheromone trap + Virtako 40WG @ 0.2 g /liter of water at 7 days interval, **T_5:** Pheromone trap + Neem oil @ 3ml/liter of water and Nitro 505EC @ 2 ml/liter of water alternatively at 7 days interval, **T_6:** Pheromone trap + Neem oil @ 3ml/liter of water and Virtako 40WG @ 0.2 g/liter of water alternatively at 7 days interval, **T_7:** Pheromone trap + NPV @ 0.2 g/liter of water at 7 days interval, **T_8:** Pheromone trap + Hand Picking + Neem oil @ 3ml/liter of water at 7 days interval, **T_9:** Pheromone trap + Hand Picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval, **T_{10}:** Pheromone trap + Hand Picking + Nitro 505EC @ 2ml/liter of water at 7 days interval. **T_{11}:** Untreated control.

In this trial, the treatment had significant effect (at least at 5% level of significance) on the number of infested plant. The results were showing the development of IPM packages against *S. litura* for safe and healthy production of tropical sugarbeet in Bangladesh. Natural control needs to be given increased emphasis as a component of the IPM approach. *S. litura* populations in groundnut fields are increasing in number and intensity, especially in fields where insecticides have been applied (Rao and Shanower, 1988).

4.5.2. Number of infested leaves 5 plant^{-1}

Infestations, particularly leaf infestation, are an important constraint to profitable production. Number of infested leaves per 5 plants varied depending upon the growth stages and indicates the plant resistance against specific insect. The lowest number of infested leaves was recorded in 21.00 in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) while the highest was 31.33 in T_{11} treatment (control) (Table 4.5.1). The second lowest number of infested leaves was 22.00 in T_9 (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment.

Table 4.5.2: Effects of integrated pest management components against larval population of tropical sugarbeet

Treatments	Larval population (5plants/plot)			Pool data	Percent efficacy over control
	March, 2021	April, 2021	May, 2021		
T_1	3.33 b	3.67 b	4.00 b	3.67	35.29
T_2	2.33 bcde	3.00 bc	3.00 bcd	2.78	50.98
T_3	1.67 cde	2.33 bc	2.33 de	2.11	62.74
T_4	1.67 cde	2.67 bc	2.33 de	2.22	60.78
T_5	2.00 bcde	2.33 bc	3.00 bcd	2.44	56.86
T_6	2.33 bcde	3.00 bc	2.67 cd	2.67	52.94
T_7	2.67 bcd	3.33 bc	3.00 bcd	3.00	47.05
T_8	3.00 bc	3.33 bc	3.67 bc	3.33	41.17
T_9	1.33 de	1.67 bc	2.00 de	1.67	70.58
T_{10}	1.00 e	1.33 c	1.33 e	1.22	78.43
T_{11}	5.33 a	6.33 a	5.33 a	5.67	0.00
CV	**33.83**	**41.44**	**21.46**	-	-
LSD (0.05)	**1.39**	**2.11**	**1.08**	-	-

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

T_1: Pheromone trap + Hand picking at 7 days interval, **T_2:** Pheromone trap + Neem oil @ 3ml/liter of water at 7 days interval, **T_3:** Pheromone trap + Nitro 505EC @ 2 ml/liter of water at 7 days interval, **T_4:** Pheromone trap + Virtako 40WG @ 0.2 g /liter of water at 7 days interval, **T_5:** Pheromone trap + Neem oil @ 3ml/liter of water and Nitro 505EC @ 2 ml/liter of water alternatively at 7 days interval, **T_6:** Pheromone trap + Neem oil @ 3ml/liter of water and Virtako 40WG @ 0.2 g/liter of water alternatively at 7 days interval, **T_7:** Pheromone trap + NPV @ 0.2 g/liter of water at 7 days interval, **T_8:** Pheromone trap + Hand Picking + Neem oil @ 3ml/liter of water at 7 days interval, **T_9:** Pheromone trap + Hand Picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval, **T_{10}:** Pheromone trap + Hand Picking + Nitro 505EC @ 2ml/liter of water at 7 days interval. **T_{11}:** Untreated control.

4.5.3. Effects of integrated pest management components on larval population

The number of larvae were collected from three different months which was statistically significant among the treatments in every month data. The highest number of larvae was recorded in April followed by May. The lowest number of larvae was observed in the month of March (Table 4.5.2).

Number of larval population varied depending upon the growth stages and indicates the plant resistance against specific insect. From the pool data, the lowest number of larval population was found (1.22) in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval) while the highest population was (5.67) in T_{11} treatment (control). The second lowest number of larvae was 1.67 in T_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment. The highest percent efficacy over control (78.43%) was recorded in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval) while the lowest 35.29 at T_1 treatment (pheromone trap + hand picking at 7 days interval) at pool data. In this trial, the treatment had significant effect (at least at 5% level of significance) on the number of larval population (Table 4.5.2). Siddiquee *et, al.*, (2017) also found the lowest (12.44) number of larval population in Nirto 505EC @ 4.5 L/ha at 15 days interval on sugerbeet field and highest percent efficacy over control was found 81.06 in the season of 2013-2014 which was close to our study.

Table 4.5.3: Effects of different integrated pest management components on the weight of beet and number of infested beet of tropical sugarbeet

Treatments	Weight of individual beet (g)	No. of infested beet / plot
T_1	741.00 ab	10.00 ab
T_2	779.67ab	8.00 abcd
T_3	794.33 ab	6.66 cd
T_4	785.33 ab	7.33 bcd
T_5	780.67ab	7.66 abcd
T_6	779.00ab	7.33 bcd
T_7	759.67ab	8.66 abcd
T_8	750.67ab	9.33 abc
T_9	807.33 ab	6.33 cd
T_{10}	814.67 a	6.00 d
T_{11}	722.67 b	10.66 a
CV	**6.20**	**24.43**
LSD (0.05%)	**81.77**	**3.32**

*Means in the same column followed by the different letters are significantly different at $p<0.05$

T_1: Pheromone trap + Hand picking at 7 days interval, **T_2:** Pheromone trap + Neem oil @ 3ml/liter of water at 7 days interval, **T_3:** Pheromone trap + Nitro 505EC @ 2 ml/liter of water at 7 days interval, **T_4:** Pheromone trap + Virtako 40WG @ 0.2 g /liter of water at 7 days interval, **T_5:** Pheromone trap + Neem oil @ 3ml/liter of water and Nitro 505EC @ 2.0 ml/liter of water alternatively at 7 days interval, **T_6:** Pheromone trap + Neem oil @ 3ml/liter of water and Virtako 40WG @ 0.2 g/liter of water alternatively at 7 days interval, **T_7:** Pheromone trap + NPV @ 0.2 g/liter of water at 7 days interval, **T_8:** Pheromone trap + Hand Picking + Neem oil @ 3ml/liter of water at 7 days interval, **T_9:** Pheromone trap + Hand Picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval, **T_{10}:** Pheromone trap + Hand Picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval. **T_{11}:** Untreated control.

4.5.4. Effects of integrated pest management components on beet weight

Beet weight can be determined the value of the sugarbeet variety at harvesting. The quality sugarbeet can produce more beet compare to other under favorable condition. The highest weight of individual beet was 814.67 g in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval) while, the lowest was 722.33 g in T_{11} treatment (control) (Table 4.5.3). The second highest weight of individual beet was 807.33g in T_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval).

4.5.5. Effects of integrated pest management components on the infested beet plot $^{-1}$

The lowest number of infested of beet was 6.00 in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval), while the highest was 10.66 in T_{11} (control) (Table 4.5.3). The second lowest number of infested beet was 6.33 inT_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval). So, the number infested beet per plot showed the significant differences among the studied integrated pest management components.

Table 4.5.4: Effects of integrated pest management components on the length and girth of beet when applied against S*pdoptera litura* in tropical sugarbeet

Treatments	Length of beet (cm)	Girth of beet (cm)
T_1	23.00 de	27.66 bc
T_2	25.66 bcde	30.66 bc
T_3	27.66 abc	37.00 abc
T_4	27.33 abc	34.66 abc
T_5	26.66 abcd	32.66 abc
T_6	26.33 abcd	31.33 bc
T_7	25.33 bcde	30.66 bc
T_8	24.00 cde	28.33 bc
T_9	28.33 ab	38.00 ab
T_{10}	29.66 a	42.66 a
T_{11}	22.00 e	26.66 c
CV	**8.38**	**20.06**
LSD (0.05%)	**3.71**	**11.19**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

T_1: Pheromone trap + Hand picking at 7 days interval, **T_2:** Pheromone trap + Neem oil @ 3ml/liter of water at 7 days interval, **T_3:** Pheromone trap + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval, **T_4:** Pheromone trap + Virtako 40WG @ 0.2 g /liter of water at 7 days interval, **T_5:** Pheromone trap + Neem oil @ 3ml/liter of water and Nitro 505EC @ 2.0 ml/liter of water alternatively at 7 days interval, **T_6:** Pheromone trap + Neem oil @ 3ml/liter of water and Virtako 40WG @ 0.2 g/liter of water alternatively at 7 days interval, **T_7:** Pheromone trap + NPV @ 0.2 g/liter of water at 7 days interval, **T_8:** Pheromone trap + Hand Picking + Neem oil @ 3ml/liter of water at 7 days interval, **T_9:** Pheromone trap + Hand Picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval, **T_{10}:** Pheromone trap + Hand Picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval. **T_{11}:** Untreated control.

4.5.6. Effects of integrated pest management components on beet length

Beet length can be determined the beet quality of the sugarbeet variety at harvesting. The quality sugarbeet can produce more beet compare to other under favorable condition. The highest length of beet was 29.66 cm in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval), while the lowest was 22.00 cm in T_{11} treatment (control) (Table 4.5.4). The second highest length of beet was 28.33 cm in T_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment.

4.5.7. Effects of integrated pest management components on beet girth

The highest girth of beet was 42.66 cm in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval), while the lowest 26.66 cm in T_{11} treatment (control) (Table 4.5.4). The second highest girth of beet was 38.00 in T_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment. Rahman *et al.*,(2017), found the highest 78.00 tha^{-1} yield in Nitro treated plot followed 72.67 t ha^{-1} by Virtako 40WG in NBSM (Natore, Bangladesh) location where as control plot was 57.67 t ha^{-1} in the season 2015-16.

Table 4.5.5: Effect of integrated pest management components on the percentage of Brix and Pol in tropical sugarbeet

Treatment	Brix (%)	Pol (%)
T_1	15.33 de	8.33 fg
T_2	16.83 bcd	9.83 cde
T_3	18.50 ab	11.40 ab
T_4	17.50 bc	11.00 abc
T_5	17.33 bc	10.66 abc
T_6	17.00 bcd	10.33 bcd
T_7	16.33 cd	9.26 def
T_8	15.66 cd	8.83 efg
T_9	18.66 ab	11.83 a
T_{10}	19.50 a	12.00 a
T_{11}	13.57 e	7.66 g
CV	**6.38**	**7.97**
LSD (0.05)	**1.84**	**1.37**

*Means in the same column followed by the different letters are significantly different at $p<0.05$.

T_1: Hand picking at 7 days interval. **T_2:** Spraying of Neem oil @ 3ml/lit of water at 7 days interval. **T_3:** Spraying of Nitro 505 EC @ 2 ml/lit of water at 7 days interval. **T_4:** Spraying of Virtako 40 WG @ 0.2 g /lit of water at 7 days interval. **T_5:** Spraying of Neem oil @ 3ml/lit of water and Nitro 505 EC @ 2 ml/lit of water alternatively at 7 days interval.**T_6:** Spraying of Neem oil @ 3ml/lit of water and Virtako 40 WG @ 0.2 g/lit of water alternatively at 7 days interval.**T_7:** Spraying of NPV @ 0.2 g/lit of water at 7 days interval. **T_8:** Hand Picking + Spraying of Neem oil @ 3ml/lit of water at 7 days interval.**T_9:** Hand Picking + Spraying of Virtako 40 WG @ 0.2 g/lit of water at 7 days interval. **T_{10}:** Hand Picking + Spraying of Nitro 505 EC @ 2ml/lit of water at 7 days interval. **T_{11}:** Untreated control.

4.5.8. Brix percentage

The highest brix was obtained 19.50 (%) in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval), while the lowest was 13.57 (%) at T_{11} treatment (control) (Table 4.5.5). The second highest brix was 18.66 (%) in T_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment.

4.5.9. Pol percentage

The highest Pol was found 12.00 (%) in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval) while, the lowest was 7.66 (%) in T_{11} treatment (control) (Table 4.5.5). The second highest Pol percent of beet was 11.83 in T_9 treatment (pheromone trap + hand picking + Virtako 40 WG @ 0.2 g/liter of water at 7 days interval) treatment. The results were showing the significant differences among the studied integrated pest managemint components on the pol% of tropical sugarbeet. The T_{10} treatment (hand Picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) was the best suited treatment in the experiment. The T_{10} treatment was high value compared to other treatment. Siddique *et al.,* (2017) found highest (14.93%, 16.32%, 15.27%) pol in Nitro 505EC treated plot in the season 2013-14, 2014-15 and 2015-16 in BSRI farm Ishurdi.

CHAPTER V

SUMMARY AND CONCLUSION

Five experiments were conducted to find out the appropriate and effective IPM practices against *Spodoptera litura*.The results showed that the sugarbeet variety Cauvery was the best suited variety and PAC-60008 was the most susceptible variety against *S. litura*. The germination percentage was the highst (94.87%) in Cauvery variety compare to other and lowest (84.62 %) was PAC-60008 variety and the LAI and % DM also high in the Cauvery variety. The resistances against insect pests were less compared to others. The highest (7.73) number of bore/plant and maximum larval population were found in PAC-60008 variety, while the lowest (2.20) number of bore/plant and minimum larval population were observed in Cauvery. The final outcome was yield and its related parameter showing positive to Cauvary and negative to PAC-60008. The Brix (18.23%) and Pol (13.45%) were highest in Cauvery and lowest (brix-14.70%, pol-11.18%) in PAC-60008. The second most favorable variety was Shubhra.

In the second experiment, toxicity of insecticides was observed on life stages of *S. litura*. Effectiveness of different doses of insecticides was tested at three different schedules i.e. after 8 h, 16 h and 24 h, respectively at 3^{rd} instar larvae of *S. litura* under laboratory condition.The lowest (0 %) mortality percentage was observed after 8 h in T_{11} (control) and T_1 (Acicarb 85WP solution) while the maximum (15%) mortality percentage of larvae were found in T_{10} (Virtako 40WG solution) followed by T_6 (Nitro 505EC solution) 12.5% . However, after 16 h and 24 h the minimum (7.5% and 17.5%) mortality percentage of larvae were observed in T_{11} (control) while, the maximum (50.0 % and

92.50%) mortality percentage of larvae were T_6 (Nitro 505EC solution) followed by 50.0 % and 90.0%) in T_{10} (Virtako 40WG).

Mortality percent increase over control varied from zero percent to more than 400 percent. The highest mortality percent of larvae increase over control was in T_6 (Nitro 505EC solution @ 2.0ml/lit of water) 428.57% followed by T_{10} (Virtako 40WG solution @ 0.2 g/lit of water) 414.28%. However, the lowest mortality percent of larvae increase over control were at T_1 (Acicarb 85 WP solution @ 3.5 g/lit of water) 300%. The lowest days of adult emergence and weight (g) of larvae against (IRS) were recorded in T_6 (19±0.5) days and (17.8±0.8) mg, respectively.

In the third experiment, the T_5 treatment [Spraying of Virtako40 WG (thiamethoxam 20% + chloraniliprole 20%) @ 0.2 g/liter of water at 7 days interval] was the best suited treatment in the field condion. The lowest number of infested plant were recorded 7.00 in T_3 treatment (Nitro 505EC) followed by 7.67 in T_5 (Virtako 40WG) while, the highest 10.33 in T_9 treatment (Control). The minimum number of infested leaves was found 11.67 in T_3 treatment (Nitro 505EC) while, the maximum 18.33 in T_9 treatment (control). The second lowest number of leaves was 13.33 at T_5 (Virtako 40WG) treatment. The lowest number of infested beet was observed 4.67 in T_3 treatment (Nitro 505EC) while, the highest 14.33 in T_9 treatment (Control). The second lowest number of infested beet was 5.33 in T_5 (Virtako 40WG) treatment.

From the pool data the lowest number of larvae per 5 plant were recorded 1.53 in T_3 treatment (Nitro 505EC @ 2.0 ml/liter of Water at 7 days interval) followed by 2.03 in T_5 (Spraying of Virtako 40 WG @ 0.2 g/liter of water at 7 days interval) treatment while the highest 9.47 in T_9 treatment (Control). The highest efficacy over control (83.80%) was

found in Nitro 505EC treating plot followed by (78.52 %%) in Virtako 40WG where as the lowest 56.58% was found in Acicarb 85WP treating plot.

The highest weight of beet was recorded 761.00 g in T_3 treatment (Nitro) while, the lowest was 693.67g in T_9 treatment (control). The second highest weight of beet was 750.67g in T_5 (Virtako 40WG) treatment. The highest Pol percentage was observed 12.33 in T3 treatment (Nitro 505EC) while, the lowest was 9.66 in T_9 treatment (control). The second highest Pol percent was 12.00 in T_5 treatment (Virtako 40WG). The T_5 treatment Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water at 7 days interval) was the best suited treatment as showing the highest Pol (12.00 %).

In the fourth experiment, The T_1 treatment (Neem oil @ 3.0 ml/liter of water at 7 days interval) was the best suited treatment of the experiment. The lowest number of infested plant were recorded 5.66 in T_1 treatment (Neem oil @ 3.0 ml/liter of water at 7 days interval) while the highest 19.33 in T_9 treatment (control). The second lowest number of infested plants was 7.33 in T_8 (pheromone trap) treatment, where as the minimum number of infested leaves were recorded 4.66 in T_8 (pheromone trap) treatment followed by 5.33 in T_1 (Neem oil) treatment, while the highest number of infested leaves was 12.60 in T_9 treatment (control).

The highest number of infested beet was observed 30.33 in T_9 treatment (control) while the lowest 11.00 in T_1 treatment (Neem oil @ 3.0 ml/liter of water at 7 days interval). The second highest number of infested beet was 27.66 in T6 (light trap) treatment.

The minumum number of bore per beet was observed 4.60 in T_1 treatment (Neem oil) followed by 4.93 in T_8 (pheromone trap) treatment, while the highest number of bore per beet 9.53 in T_9 treatment (control).

The lowest number of larvae per 5 plants were recorded 1.58 in T_1 treatment (neem oil @ 3ml/liter of water at 7 days interval) followed by 1.94 in T_8 treatment (pheromone trap), while the highest number of larvae was 10.11 inT_9 treatment (control). The highest efficacy over control was 84.34% in T_1 treatment (Neem oil) followed by 80.78 in T_8 (pheromone trap). Moreover, yield and yield contributing parameters also high in the Neem oil treatment.

So, the final experiment the development of IPM packages against *S. litura* for safe and hazards free production of tropical sugarbeet the T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) was the best suited treatment in the experiment. The lowest numbers of plant were recorded at 4.33 in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC) while the highest 9.00 in T_{11} treatment (control). The second lowest number of plant was 5.00 in T_9 (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval) treatment.The minimum number of infested leaves was observed in 21.00 in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC) followed by 22.00 in T_9 (pheromone trap + hand picking + Virtako 40WG) treatment, while the highest was 31.33 in T_{11} treatment (control).

From the pool data, the lowest number of larval population was found (1.22) in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC) followed by 1.67 in T_9 treatment (pheromone trap + hand picking + Virtako 40WG) treatment, while the highest larval population was (5.67) in T_{11} treatment (control). The highest percent efficacy over control (78.43%) was recorded in T_{10} treatment (pheromone trap + hand picking +

Nitro505EC), while the lowest 35.29% in T_1 treatment (pheromone trap + hand picking at 7 days interval).

The highest weight of individual beet was 814.67 g in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2ml/liter of water at 7 days interval) while, the lowest was 722.33 g in T_{11} treatment (control) (Table 4.5.3). The second highest weight of individual beet was 807.33g in T_9 treatment (pheromone trap + hand picking + Virtako 40WG @ 0.2 g/liter of water at 7 days interval).

The highest brix was obtained 19.50 % in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval), while the lowest was 13.57 % in T_{11} treatment (control) (Table 4.5.5). The maximum Pol was found 12.00 (%) in T_{10} treatment (pheromone trap + hand picking + Nitro 505EC) followed by 11.83% in T_9 treatment (pheromone trap + hand picking + Virtako 40 WG) treatment, while, the lowest was 7.66 (%) in T_{11} treatment (control). Moreover, yield and yield contributing pararameters also high in T_{10} treatment. The T_{10} treatment (hand Picking + Nitro 505EC @ 2.0 ml/liter of water at 7 days interval) was the best suited and high value treatment compared to others.

CONCLUSIONS

Based on the findings of the five experiments, the following conclusions can be made-

- Among the twelve sugarbeet variety Cauvery was the best suited variety against *Spodoptera litura*, while PAC-60008 was the most susceptible.
- The sugarbeet caterpillar *S. litura* infestation was high in PAC-60008 variety and lowest in Cauvery. Yield and its related parameter also showed positive relation in Cauvary and negative to PAC-60008.
- Spraying of Nitro 505EC (cypermethrin + chloropyriphos) @ 2.0 ml/liter of water provided the lowest days of adult emergence (19±0.5) and weight (g) (17.8±0.8) of larvae.
- The weight larva was the lowest when the mortality percentage was the highest. The weight of larvae increased with the decreasing mortality percentage.
- The days of adult emergence were the lowest when the mortality percentage was the highest. The days of adult emergence increased with the decreasing mortality percentage.
- The highest (92.50 %) mortality percentage at 3rd instar larvae of *S. litura* was found in Spraying of Nitro 505EC solution in the petridish under laboratory condition.
- In the field condition Spraying of Virtako 40WG (thiamethoxam 20% + chlorantraniliprole 20%) @ 0.2 g/liter of water at 7 days interval was found most effective chemical insecticide against sugarbeet caterpillar *S. litura*, Nitro 505EC was found second effective and Dursban 20EC was found thirdeffective insecticide.

- Among botanicals, non-chemicals and bio-pesticides usage of Neem oil @ 3.0 ml/liter of water at 7 days interval and pheromone trap were found more effective against *S. litura,* but lower than chemical insecticides. In case larval population, percent efficacy over control was highest (84.34%) in Neem oil treatment.

- Finally, for safe and hazards free production of tropical sugarbeet IPM package 10 (T_{10}) (use of pheromone trap + hand picking + Nitro 505 EC @ 2.0 ml/liter of water at 7 days interval) was found most effective against S*pdoptera litura.*

Considering the results of the present study, it can be concluded that IPM Package 10 may be used for the management of sugarbeet cater pillar.

RECOMMENDATIONS

Based on the findings and inadequacies of the study, the followings recommendations were made:

- The integrated management practice found most effective and needed to conduct further study considering on a large scale under farmers' field condition.
- An integrated practice comprising the application of Nitro 505 EC at an interval of 7 days plus biological control which has not been integrated, may be designed for further study.
- The findings related to resistance development are not conclusive, which may be undertaken on a comprehensis basis.
- Scantly of research on sugarbeet in Bangladesh perspectives, so further study is also needed in different locations of Bangladesh for accuracy of the results obtained from the present experiments.

CHAPTER VI

REFERENCES

Abdullah, M., Begum, M. and Siddiki, N.A. (2015). Development of some management approaches against sugarbeet caterpillar (*Spodoptera litura* Fab.) in sugarbeet. *Bangladesh J. of Sugarcane*. **36**(1): 29-21.

Abe, J., Yoshikawa, J.A.H. and Tsuda, C.(1986). Reproductive barriers in sugarbeet and its wild relatives of the section *vulgaris*, the genus *Beta*. *J.* Fac. of Agri. Hokkaido University, **63**(1):40-48.

Abhinay, T., Varinder, S., Amarjeet, K. and Sanehdeep, K. (2014). Suppression of cellular immune response in *Spodoptera litura* (Lepidoptera: Noctuidae) larvae byendophytic fungi *Nigrospora oryzae* and *Cladosporium uredinicola*. *Annals Entomol. Soc. America,* **107**(3):674-679

Alberta Agriculture, Food and Rural Development. (1998). http://www.agric.gov.a.ca/agdex/600

Amin, M.R., Tithi, D.A. and Kwon, Y.J. (2011). Characteristics of three cotton varieties and their impact on feeding and growth of cotton armyworm. *Entom. Res.* **41**(4):151-156.

Amr, A.H.R. and Ghaffar, M.S.A. (2010). The economic impact of sugarbeet cultivation in new lands (Study of Al-Salam Canal Area Status). Aust. *J. Basic & Appl. Sci.,* **4** (7): 1641-1649.

Anju, B. and Srivastava, R.P. (2012). Compatibility and toxicity of plant oils and insecticide mixtures against larvae of tobacco caterpillar, *Spodoptera litura* Fabricius. *J. of Insect Sci*, **25**(3):318-323.

Anonymous. (1992). Tropical sugarbeet. Seeds Division. 1170/27, Revenue Colony, Shivajinagar, Pune, India. p.6.

Anonymous. (1999). Agribusiness Handbooks, Vol. 4: Sugar Beets / White Sugar. FAO. p.35.

Anonymous. (2004). Sugar beet cultivation in Bangladesh. Syngenta Bangladesh Ltd. p.4.

Anonymous. (2005). Tropical Sugar beet production technology, Soil and Crop Management Studies, Tamil nadu Agricultural University, Coimbatore, India. p.10.

Anonymous. (2010). Research report on vegetable crops 2009-2010. Horticulture Research Centre, BARI, Gazipur. p. 215

Ansari, M.A., Pawar, A.D.and Ahmed, S.N. (1987). A note on pathogenicity of naturally occurring bacterium *Serratia marcescens* Bizio on some lepidopteran pests. *Plant Protection Bulletin*, **39**(3):27-28.

Arrington, L. J. (1966). Beet sugar in the West; a history of the Utah-Idaho Sugar Company, 1891–1966. University of Washington Press. p 36.

Asadi, M. (2007). Beet-sugar handbook. Hoboken, New Jersey: John Wiley & Sons. Pp. 22-24.

Baloach, M.S.,Shah, I. H., Hussain, I. and Abdullah, K. (2002). Low sugar production in Pakistan: causes and remedies. *Pak. Sugar J*. **17**(5): 13-15.

Bichsel, S. E. (1987). An overview of the U.S. sugar beet industry. Proceedings of the Symposium on the chemistry and processing of sugar beet. Denver, Colorado. Pp. 108.

Bhatnagar, V.S., Pawar, C.S., Jadhav, D.R. and Davis, J.C.(1985). Mermithid nematodes as parasites of Heliothis sp. and other crop pests in Andhra Pradesh, India. Proc. Indian Academy of Sciences. *Animal Science*, **94**:509-515.

BRIDGE (Biotechnology Research for Innovation, Development and Growth in Europe) (1993). Safety Assessment of the Deliberate Release of Two Model Transgenic Plants. Oilseed Rape and Sugar Beet. European Community funded BRIDGE project. pp 123.

Braune, H.J.(1982). Effect of structure of host egg mass on the effectiveness of egg parasite of *Spodoptera litura* (F.) (Lepidoptera: Noctuidae). Western Samoa, Drosera, 1:7-16.

Brown, E.S. and Dewhurst, C.F. (1975). The genus *Spodoptera* (Lepidoptera, Noctuidae) in Africaand the Near East. *Bulletin of Entom. Res.* **65**(2):221-262.

BSRI (Bangladesh Sugarcrop Research Institute). (2005). Sugar beet cultivation in Bangladesh. Annual Report. p.10.

Buzanov, I. F. (1967). Scientific and technical progress in beet growing. *Vestnik Sel' skokhozy aystvennoy Nauki.* **13**: 21–26.

CABI. (2010).Crop protection compendium: global module. Commonwealth Agricultural Bureau International, Wallingford, UK. http://www.cabi.org/compendia/cpc/.

Campbell, L. G. and Klotz, K.L.(2007). Characterizing sugerbeet varieties for post-harvest storage losses is complicated by environmental effects and genotype x environment interactions. *Can. J. Plant Sci*. **87:** 121-127.

Canadian Federation of Agriculture. (1998). Agriculture in Canada. p. 66.

Canadian Sugar Beet Producers Association. (1997). Update on the Canadian Sugarbeet Industry to CFA for their Annual Meeting Report. p. 98

Capistrano-Gossmann, G. G., Ries, D., Holtgräwe, D., Minoche, A., Kraft, T., Frerichmann, S.L.M., Rosleff Soerensen, T., Dohm, J. C. and González, I. (2017). Crop wild relative populations of *Beta vulgaris* allow direct mapping of agronomically important genes. *Nature Communications*. **8**: 15708.

Chatterjee, P.B,. Nayak, D.K. (1987). Occurrence of *Spodoptera litura* (Fabr.) as a new pest of sugar-beet in West Bengal. Pesticides. 21:21-22.

Chatterjee, M.L. and Mondal, S. (2012). Sustainable management of key lepidopteran insect pests of vegetables. *Acta Horticulaturae*. 958:147-153.

Chari, M.S., Bharpoda, T.M. and Patel, S.N. (1985). Studies on integrated management of *Spodoptera litura* Fb. in tobacco nursery. *Tobacco Res.* **11**(2):93-98.

Chiu, S.C, Chou, L.Y. (1976). Hymenopterous parasitoids of *Spodoptera litura* Fab. *J of Agric Res. of China*, **25**(3):227-241.

Chu, Y.I.and Chu, C.M.(1975). Life history and the effect of temperature on the growth of *Eocanthecona furcellata* (Wolff). *Plant Protection Bulletin.* **17**(1):99-114.

Cooke, D. A. and Scott, R.K. (1993). The Sugar beet crop. Chapman and Hall Publishers. p. 675.

De Bock, T.S.M. (1986). The genus *Beta*: domestication, taxonomy and interspecific hybridization for plant breeding. *Acta Horticulurae.* **182**:35-343.

Deng, G.Y. and Jin, M.X. (1985). Study on a predacious katydid, *Conocephalus* sp. *Chinese J. of Bio Control.* **1**(4):8-11.

Dowling, R. N. (1928). Sugar Beet and Beet Sugar: Ernest Benn Limited, London. Pp. 33.

Dohm, J. C., Minoche, A. E., Holtgräwe, D., Capella-Gutiérrez, S., Zakrzewski, F., Tafer, H., Rupp, O., Sörensen, T. R., Stracke, R. (2013). The genome of the recently domesticated crop plant sugar beet (*Beta vulgaris*). *Nature*. **505** (7484): 546–549.

Duke, J. A. (1983). Handbook of Energy Crops: *Beta vulgaris* L.Centre for New Crops and Plant Products, Purdue University West Lafayette, Indiana USA. Pp. 345-369.

Feakin, S.D. (1973). Pest control in groundnuts. PANS Manual No. 2. London, UK: ODA. Vol. 2. p.123.

Fernald, M.L. (1950). Gray's Manual of Botany, 8th Ed. New York, Van Nostrand Reinhold. Pp.590-600.

Fiset, L. (1999). Thinning, topping and loading: Japanese Americans and Beet Sugar in World War II. The Pacific Northwest Quarterly. **3** (90): 123–139.

FAO. (1999). Agribusiness Handbooks, Sugar Beets : White Sugar. Food and Agricultural Organization of the United Nations, Rome. **4**:109-110.

FAO. (2009). Agribusiness Handbooks, Sugar Beets: White Sugar. Food and Agricultural Organization of the United Nations, Rome. **36**:172-179.

FAO. (2011). Production Year Book : Statistics. Food and Agricultural Organization of the United Nations, Rome. **38**:62-71.

Ford-Lloyd, B.V. (1991). Conservation of sugarbeet genetic resources: Provision of genes for the future. Beet Review - British Sugar, **59** (1): 98-109.

Forster, V., Marrese, D., Staska, K., Trinks, K., and Stander, J.R. (1997). Petition for Determination of Nonregulated Status: Glufosinate Tolerant Sugar Beet, Transformation Event T120-7. AgrEvo USA Comapany, Wilmington, Delaware. pp.67.

Funk, A., Galewski, P. and McGrath, J.M. (2018). Nucleotide-binding resistance gene signatures in sugar beet, insights from a new reference genome. *The Plant J.* **95** (4): 659–671.

Gadhiya, H.A., Borad, P.K. and Bhut, J.B. (2014). Effectiveness of synthetic insecticides against *Helicoverpa armigera* (Hubner) Hardwick and *Spodoptera litura* (Fabricius) infesting groundnut. *The Bioscan*. **9**(1):23-26.

George, R. (1873). Something about sugar: its history, growth, manufacture and distribution. San Francisco, *J. J. Newbegin*. Pp. 233-235.

Godfrey, M. C. (2007). Religion, politics, and sugar: the Mormon Church, the federal government, and the Utah-Idaho Sugar Company, 1907-1921. All Usu Press Publications. Logan, Utah: Utah State University Press. pp. 77-79.

Gupta, S.D. and Bhupendra, K. (2014). Bioefficacy of *Beauveria bassiana* (Balsamo) against third instar larvae of *Spodoptera litura* (Far.). *International J. of Plant Sci*. **9**(1):97-100.

Hanelt, P., Büttner, R., Mansfeld, R. and Kilian, R. (2001). Mansfeld's Encyclopedia of Agricultural and Horticultural Crops. *Springer*. pp. 235–241.

Hecker, R. J., (1978). Recurrent and reciprocal recurrent selection in sugar beet. *Crop Science*, **18** (4): 805-809.

Hecker, R.J., and Helmerck, (1985). Sugar beet breeding in the United States. *In Progress in Plant Breeding*, **1**: 37-61.

Heitkam, T. and Schmidt, T. (2009). BNR – a line family from *Beta vulgaris*– contains a RRM domain in open reading frame 1 and defines a L1 sub-clade present in diverse plant genomes. *The Plant J.* **59**(6): 872–882.

Hill, G. and Langer, R. H. M. (1991). Agricultural plants. Cambridge, UK: Cambridge University Press. pp. 197–199.

Holloway, J.D.(1989). The moths of Borneo: family Noctuidae, trifine subfamilies: Noctuinae, Heliothinae, Hadeninae, Acronictinae, Amphipyrinae, Agaristinae. *Malayan Nature Journal*, **42**(2-3):57-228.

Iqbal, M. A. and Saleem, M. A. (2015). Sugar Beet Potential to Beat Sugarcane as a Sugar Crop in Pakistan. American-Eurasian *J. Agric. & Environ. Sci.*, **15**(1): 36-44.

Islam, A.K., Razzak, M.A., Alam, M.J., Sohel, M.A.T., Roy, H.P., Rahman, M.S. and Rahman, M.K. (2014). Performance of some exotic tropical sugarbeet genotypes under agro-climatic conditions of Bangladesh. *Bangladesh J. Sugarcane*. **35**:1-9.

Islam, M.J., Begum, M.K., Arefin, M.S., Shanta, F.H., Islam, S., Razzak., M.A. and Reza, M.E. (2015). Leaf characteristics and chlorophyll concentration of different sugar beet genotypes at different harvesting stages. *Bangladesh J. Sugarcane.* **35**:22-28.

Jayanth, K.P. and Nagarkatti, S. (1984). Record of true parasitism in Peribpa orbata (Wied.) (Diptera: Tachinidae). *Entomon*. **9**(1):77-78.

Joshi, B.G., Sitaramaiah, S., Satyanarayana, S.V.V. and Ramaprasad, G. (1979). Note on natural enemies of *Spodoptera litura* (F.) and *Myzus persicae* (Sulz.) on flue-cured tobacco in Andhra Pradesh. *Science and Culture.* **45**(6):251-252.

Kapur, M.L. and R.S. Kanwar (1990). Phosphorus fertilization of sugar beet in subtropical India. *J. of Sugarbeet Res.,* **27**: 11-19.

Kaufman, C.K. (2008). Salvation in Sweetness? Sugarbeets in antebellum America. Vegetables: Proc. Oxford Symposium on Food and Cookery: pp. 95–104.

Kannan, R., Rajamanickam, C., Annamalai, T., Kirubakaran, S.A., Sengottayan, S. N. (2014). Biocontrol efficacy of protoplast fusants between *Bacillus thuringiensis* and *Bacillus subtilis* against *Spodoptera litura* Fabr. Archives of Phytopathology and Plant Protection, **47**(11):1365-1375.

Kondo, E. and Ishibashi, N.(1984). Infectivity and multiplication of Steinernema feltip (str. Mexican) on the common cutworm, *Spodoptera litura. Japanese J. Applied Entom. and Zoology*. **28**(4):229-236.

Koyikkal, S. (2013). Chemical Process Technology and Simulation. PHI Learning Pvt. Pp.8

Kranz, J., Schmutterer, H. and Koch, W. (1977). Diseases, Pests and Weeds in Tropical Crops. Verlag Paul Parey, Germany. pp. 617-620.

Krishnaiah, K., Ramakrishnan, N. and Reddy, P.C. (1985). Control of *Spodoptera litura* Fab. on blackgram by nuclear polyhedrosis virus. *Indian J. Agril. Sci.* **55**(12):775-776.

Letschert, J. P. W. (1994). Taxonomy of *Beta* section *Beta*. *J. Sugar Beet Research*. **31**:69-85.

Limb, R. (2008).The effective communication of agricultural R&D output in the UK beet sugar industry. Proc. South African Sugar Technology Association. 81 pp. 107–115.

Li, S.P. and Wenn, C.S.(1987). *Nosema liturae* sp. n., a new species of microsporidia from the cotton leaf worm, *Spodoptera litura*. *Scientia Agricultura Sinica,* **20**(1):71-74.

Magnuson, T. A. (1918). History of the beet sugar Industry in California. Annual Publication of the Historical Society of Southern California. **11** (1): 68–79.

Malone, L.A. and Wigley, P.J. (1980). The distribution of *Nosema carpocap*sp, a protozoan pathogen of the codling moth, *Cydia pomonella* (Lepidoptera: Tortricidae), in New Zealand. New Zealand Entom., **7**(2):151-153

Marimuthu, S.(2008). Effect of Pongamia glabra oil on cut worm, *Spodoptera litura* and its natural enemies in tomato. *J. of Ecobiology,* **23**(1):61-66.

May, M. J.,Hampion, G.T., Dewar, A.M., Qi, A. andPidgeon, J.D. (2005). Management of genetically modified herbicide-tolerant sugar beet for spring and autumn environmental benefit. *Proc. Biol. Sci.* **27** (1559): 111–119.

McFarlane, J. S., Skoyen, I. O. and Lewellen, R. T. (1972). Performance of sugarbeet hybrids as diploids and triploids. *Crop Sci.,* **12** (1): 118-119.

McFarlane, J. S. (1975). Naturally occurring hybrids between sugarbeet and *Beta macrocarpa* in the Imperial Valley of California. *J. American Soc. of Suger Beet Tech*. **18**: 245-251.

Mike, A. (2009). Roundup ready crops prove to be a hit in the USA. Farmers Weekly. Archived from the original on 2011-11-24. Pp.45

Mohammad, M., Uma, S. (2008). Sub-lethal effects of SpltMNPV infection on developmental stages of *Spodoptera litura* (Lepidoptera: Noctuidae). *Biocontrol Sci. and Tech*., **18**(4):431-437.

Munir, A., Mushtaq, A., Saleem and Mushtaq, A. (2005). Time-oriented mortality in leafworm, *Spodoptera litura*(Lepidoptera: Noctuidae) by some new chemistry insecticides. *Pak. Entomon.* **27**(1):67-70.

Naeem, A., Samiullah, S.S.A., Muhammad, R., Abdul, W. and Muhammad, A. (2014). Resistance of *Spodoptera litura* (Lepidoptera: Noctuidae) to profenofos: relative fitness and cross resistance. *Crop Protect,* **58**:49-54.

Nakasuji, F., Yamanaka, H. and Kiritani, K. (1976). Predation of larvae of the tobacco cutworm *Spodoptera litura* (Lepidoptera, Noctuidae) by Polistes wasps. Kontyu, **44**(2):205-213.

Narayanan, K. and Jayarai, S. (1979). *Spodoptera litura* (F.) as a host for Nosema sp. *Current Sci.*, **48**:276.

Narayanan, K. (1985). Susceptibility of *Spodoptera litura* (F) to a granulosis virus. *Current Sci.*, **54**(24):1288-1289.

National Agricultural Statistics Service (NASS), Agricultural Statistics Board, U.S. Department of Agriculture. (2006). Crops & Plants – Field Crops: Sugarbeet. Washington, DC. Archived on 2006-10-03.

National Agricultural Statistics Service (NASS), Agricultural Statistics Board, U.S. Department of Agriculture. (1997). Crop Production - Acreage - supplement. Washington, DC. Pp. 213-223.

Navasero M.V. and M.M. Navasero. (2011). Farm-level production and utilization of nuclear polyhedrosis virus of the common cutworm, *Spodoptera litura* Fabricius (Noctuidae, Lepidoptera) for tomato production. **In:** Manual of integrated production and pest management in processing tomato S.M.F., Calumpang, and D.P., Callo, Jr, (Eds.). Department of Agriculture, KASAKALIKASAN, ASEAN IPM, NCPC, UPLB and CHARM-2 Project. pp. 316.

Nayak, S., Chatterjee, S.K. and Majumdar, G. (1987) Carbohydrates of an amphistome trematode ceylonocotyle scoliocoelium. *Environment & Ecology*, pp. 162-164.

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). (1998). Town and Country Ontario, November, 7-10. p. 45.

Paesold, S., Borchardt, D., Schmidt, T. and Dechyeva, D. (2012). A sugar beet (*Beta vulgaris* L.): Fish karyotype for chromosome and chromosome-arm identification, integration of genetic linkage groups and analysis of major repeat family distribution. *The Plant J.* **72** (4): 600–611.

Panella, L. (1996). Report on the status of *Beta* Germplasm in the United States. Sugar beet crop germplasm committee, pp.41.

Patel, H. K., Patel, N. G. and Patel, V. C. (1971). Quantitative estimation of damage to tobacco by the leaf-eating caterpillar, *Prodenia litura*., PANS. pp. 17: 202-205.

Patnaik, H.P. (1998). Pheromone trap catches of *Spodoptera litura* F. and extent of damage on hybrid tomato in Orissa. Advances in IPM for horticultural crops. Proc. First national symposium on pest management in horticultural crops: environmental implications and thrusts, Bangalore, India, 15-17 October 1997. Pp. 68-72.

Patil, A.S., Salunkhe, A.N., Pawar, B.H., Ghodke, P.V., Shivankar,S.B., Zende,N.B., Shewate,S.R. and Patil, D.J. (2007). Sugar beet cultivation in tropical India: A new experience. Proc. 68th Annual Conf., 22–24 August 2007, STAI, New Delhi. 85–111.

Patil, M.U., Kulkarni, A.V. and Omkar, G.(2014). Evaluating the efficacy of novel molecules against soybean defoliators. *The Bioscan,* 9(2):577-580.

Peter, S. C. (2009). De-icing Roads with De-sugared Beet Molassis (sic). CAS Communications. Pp. 123-124.

Phadke, C.H. and Rao, V.G.(1978). Studies on the entomogenous fungus *Nomuraea rileyi* (Farlow) Samson I. Current Sci. **47**(14):511-512.

Poggi, E. M. (1930). The German sugar beet industry. *Economic Geography*. **6**(1): 81–93.

Prasad, N.V.V.S.D., Lakshmi, M.S.M. and Rao, N.H.P. (2009). Comparative performance of light trap and pheromone traps for monitoring of bollworms in cotton under rainfed situations. *Indian J. Ecology*, **36**(1):79-83.

Rahman, M.A., Samad, M.A., Saifuzzaman, M., Zaman, M.A.H.S. and Chowdhyry, M.Z.A. (2007). Procedure for removal of soil acidity for crop production. Wheat Research centre, BARI, Gazipur, Bangladesh. p.9.

Rahman, M.A., Siddiquee, M.N.A., Islam, M.S., Reza, M.E., Alam, K.S. and Begum, M. (2017). Effects of new organophosphate and synthetic pyrethroid insecticides in controlling sugar beet caterpillar of Bangladesh. *Bangladesh J. Sugarcane.* **38**:21-30.

Rao, P.G.M.V., Saralamma, S. and Sudhakar, K. (2004). Management of the tobacco leaf eating caterpillar *Spodoptera litura* Fabricius in *cigarette nattu* tobacco. *Tobacco Res*, 30: 1-10.

Ramakrishnan, N., Saxena, V.S. and Dhingra, S.(1984). Insecticide-resistance in the population of *Spodoptera litura* (F.) in Andhra Pradesh. *Pesticides,* **18**(9):23, 27.

Ranga, R.G.V. and Shanower, T.G. (1989). A survey of groundnut insect pests in Andhra Pradesh, post rainy season, 1987-1988. *Int. Arachis Newsletter*, **4**:8-10.

Rashid, M.M. (1999). Sabji Biggan (in Bengali), Rashid Publishing House, 94, Old DOHS, Dhaka. p. 455.

Robert M.H. (2014). History of Sugar Beet Production and Use. University of Nebraska. Retrieved April 1, 2014. p. 36.

Sahayaraj, K. (2011). Aqueous and water extracts of chosen botanicals on *Helicoverpa armigera* Hubner and *Spodoptera litura* Fab. *Int. J.Agric. Tech*, **7**(2):339-347.

Sarah, M. (2008). That beet is sweet. Statistics Canada. Archived from the original on July 6, 2011.

Sathe, T.V.(1987). New records of natural enemies of *Spodoptera litura* (Fab.) in Kolhapur, India. *Current Sci,* **56**(20):1083-1084.

Schwichtenberg, K., Wenke, T., Zakrzewski, F., Seibt, K. M., Minoche, A., Dohm, J. C., Weisshaar, B., Himmelbauer, H. and Schmidt, T. (2016). Diversification, evolution and methylation of short interspersed nuclear element families in sugar beet and related Amaranthaceae species. *The Plant J.* **85** (2): 229–244.

Scott, R. K. and Wilcockson, S. J. (1976). Weed biology and growth of sugar beet. *Annals of Applied Biology*, **83** (2): 331-335.

Seth, R.K., Kaur, J.J., Rao, D.K., Reynolds, S.E. (2004). Effects of larval exposure to sublethal concentrations of the ecdysteroid agonists RH-5849 and tebufenozide (RH-5992) on male reproductive physiology in *Spodoptera litura. J. Insect Physiology.***50** (6): 505-517.

Shahout, H.A., Xu, J.X., Qiao, J. and Jia, Q.D.(2011). Sublethal effects of methoxyfenozide, in comparison to chlorfluazuron and beta-cypermethrin, on the reproductive characteristics of common cutworm *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae). *J. Entomol. Res. Soci.* **13**(3):53-63.

Smith, G. A. (1987). Sugar beet: Principles of Cultivar Development. Fehr, W.R. (ed.) MacMillan Publishing Company, pp.577-625.

Stander, J.R. (1995). Letter to USDA/APHIS providing rational for sugar beet to be a crop considered under notification. pp. 6.

Stephen, O.D. and Stephen B.P. (2008). Glyphosate: a once-in-a-century herbicide: Mini-review. *Pest Manag. Sci*. **64**:319–325.

Siddiquee, M.N.A., Rahman, M.A., Islam, M.S., Reza, M.E., Ahmed, T., Alam, K.S. and Begum, M. (2017). Development of integrated management approaches against *Spodoptera litura* in tropical sugar beet of Bangladesh. *Bangladesh J. Sugarcane* **38**:1-13.

Siddaramaiah, A.L., Narendrappa, T. and Panchabhavi, K.S. (1986). Occurrence and severity of *Metarrhizium anisopliae* on *Spodoptera litura* Fb. in groundnut field. Current Research, University of Agricultural Sciences, Bangalore. **15**(5-6):48-49.

Suganthy, M. and Sakthivel, P. (2013). Field evaluation of biopesticides against tobacco caterpillar, *Spodoptera litura* Fab. Infesting *Gloriosa superba* (Linn.). *J. of Biopesticides,* **6**(2):90-95.

Sugar Beet Research and Education Board. (1998). Facts about Sugar Beets and Beet Sugar. http://www.sbreb.org/brochures.

Swaran, D., Hegde, R.S., Deepika, S. and Parmar, B.S. (2006). Comparative efficacy of neem oil micro and macro-emulsions against some lepidopterous pests. *Pesticide Res J.* **18**(1):24-27.

Taussig, F. W. (1912). Beet Sugar and the Tariff. *The Quarterly J. Economics*. **26**(2):189–214.

Terrell, E. E. (1986). A Checklist of Names for 3,000 Vascular Plants of Economic Importance. USDA. Agricultural Handbook. p. 505.

Trivedi, T.P._(1988). Incidence of caterpillars on potato in Kolar, Karnataka. Current Research - University of Agricultural Sciences (Bangalore), **17**(9):121.

Tsai, S.Y., Hwang, G.H. and Dingh, T. (1978). Some insect viruses discovered in China. *Acta Entomol. Sinica*, 21:101-102.

Tuan, S.J., Lee, C.C. and Chi, H. (2014). Population and damage projection of *Spodoptera litura* (F.) on peanuts (*Arachis hypogaea* L.) under different conditions using the age-stage, two-sex life table. *Pest Manage Sci*, **70**(5):805-813.

USDA National Genetic Resource Program. (2001). National Plant Germplasm System: *Beta* http://www.ars-grin.gov/npgs/cgc_reports/beta/ch4.html.

USDA (United States Department of Agriculture). (2009). Sugarbeet Archived at the Wayback Machine from a University of California. p. 45.

United States Department of Agriculture. (2011). Sugar: World Markets and Trade. FAS Information. p. 78.

Van Geyt, J. P. C., Lange, W., Oleo, M. and De Bock, Th.S.M.(1990). Natural variation within the genus *Beta* and its possible use for breeding sugar beet: A review. *Euphytica* **49**:57-76.

Venkateswarlu, U., Madhumathi, T. and Rao, P.A.(2005). Relative toxicity of novel insecticides against insecticide resistant Guntur strain of Spodoptera litura (Fab.) on cotton in Andhra Pradesh. *Pesticide Res. J*., **17**(1):33-35.

Wang, Y.Y., Li,B.P., Gao, X.W., Meng, L.(2014). Effects of the bacterium *Empedobacter brevis* on development, survival and fecundity in *Meteorus pulchricornis* (Hymenoptera: Braconidae). *J. of Nanjing Agricultural University*, **37**(1):75-80.

Watanabe, H.(1976). A Nosema species of the Egyptian cotton leafworm, *Spodoptera litura* (Lepidoptera): its morphology, development, host range, and taxonomy. *J. of Invertebrate Path.*, **28**(3):321-328.

Watson, L., and Dallwitz, M.J.(1992). The Families of Flowering Plants: Descriptions, Illustrations, Identification, and Information Retrieval. Version: 15th October 1998. Pp. 23-25.

Weber, B., Heitkam, T., Holtgräwe, D., Weisshaar, B., Minoche, A. E., Dohm, J. C., Himmelbauer, H. andSchmidt, T. (2013). Highly diverse chromoviruses of *Beta vulgaris* are classified by chromodomains and chromosomal integration. *Mobile DNA.* **4** (1): 8.

Weber, B., Wenke, T., Frömmel, U., Schmidt, T. and Heitkam, T. (2010). The Ty1-copia families SALIRE and Cotzilla populating the *Beta vulgaris* genome show remarkable differences in abundance, chromosomal distribution, and age. *Chromosome Res*. **18** (2): 247–263.

Weed Seed Order (1986). Canada Seeds Act. p. 88

Wiersema, J.H. and León, B. (1999). World Economic Plants A Standard Reference. CRC Press LLC, pp. 75-76.

Wightman, J.A., Dick, K.M., Ranga, R.G.V., Shanower, T.G. and Gold, C.S. (1990). Pests of groundnut in the semi-arid tropics. Insect Pests of Food Legumes. S.R. Singh (ed.). New York, USA: John Wiley & Sons, pp. 243-322.

Wollrab, C., Heitkam, T., Holtgräwe, D., Weisshaar, B., Minoche, A. E.; Dohm, J. C., Himmelbauer, H. and Schmidt, T. (2012). Evolutionary reshuffling in the errantivirus lineage elbe within the *Beta vulgaris* genome. *The Plant J*. **72** (4): 636–651.

Wu, G., Feng, R. and Shui, Q. (2016). Effect of osmotic stress on growth and osmolytes accumulation in sugar beet (*Beta vulgaris* L.) plants. *Plant Soil Environ*. **62**: 189-194.

Yang, S., Yang, S.S., Sun, W., Lv, J.P. and Kuang, R.P.(2009). Use of sex pheromone for control of *Spodoptera litura* (Lepidoptera: Noctuidae). *J. Entomol. Res. Soci.*, **11**(1):27-36.

Youshima, T., Tamaki, Y., Kamano, S. and Oyama, M. (1974). Field evaluation of synthetic sex pheromone 'Litlure' as an attractant for males of *Spodoptera litura* (F.) (Lepidoptera: Noctuidae). *Applied Entomol. and Zoo*., **9**:147-152.

Zakrzewski, F., Weber, B. and Schmidt, T. (2013). A Molecular cytogenetic analysis of the structure, evolution, and epigenetic modifications of major DNA sequences in centromeres of *Beta species*. *Plant Centromere Bio.*pp. 39–55.

Zaz, G.M. and Kushwaha, K.S.(1983). Quantitative incidence of tobacco caterpillar, *S. litura* (F.) and related natural enemies in cole crops. *Indian J. Entomol.,* **45**:201-202.

Zhou, Z.S. (2009). A review on control of tobacco caterpillar, *Spodoptera litura*. *Chinese Bulletin of Entomol.*, **46**(3):354-361.

Zhou, Z., Chen, Z.and Xu, Z. (2010). Potential of trap crops for integrated management of the tropical armyworm, Spodoptera litura in tobacco. *J of Insect Sci.*, **10**(1) 117,

Zhang, J., Chen, F., Liu, L., Peter, H. Cooke, Kevin, B. and Hicks. (2008). Performance Enhancement of Poly(lactic acid) and sugar beet pulp composites by improving interfacial adhesion and penetration. *Ind. Eng. Chem. Res*. **47**(22): 8667–8675.

CHAPTER VII

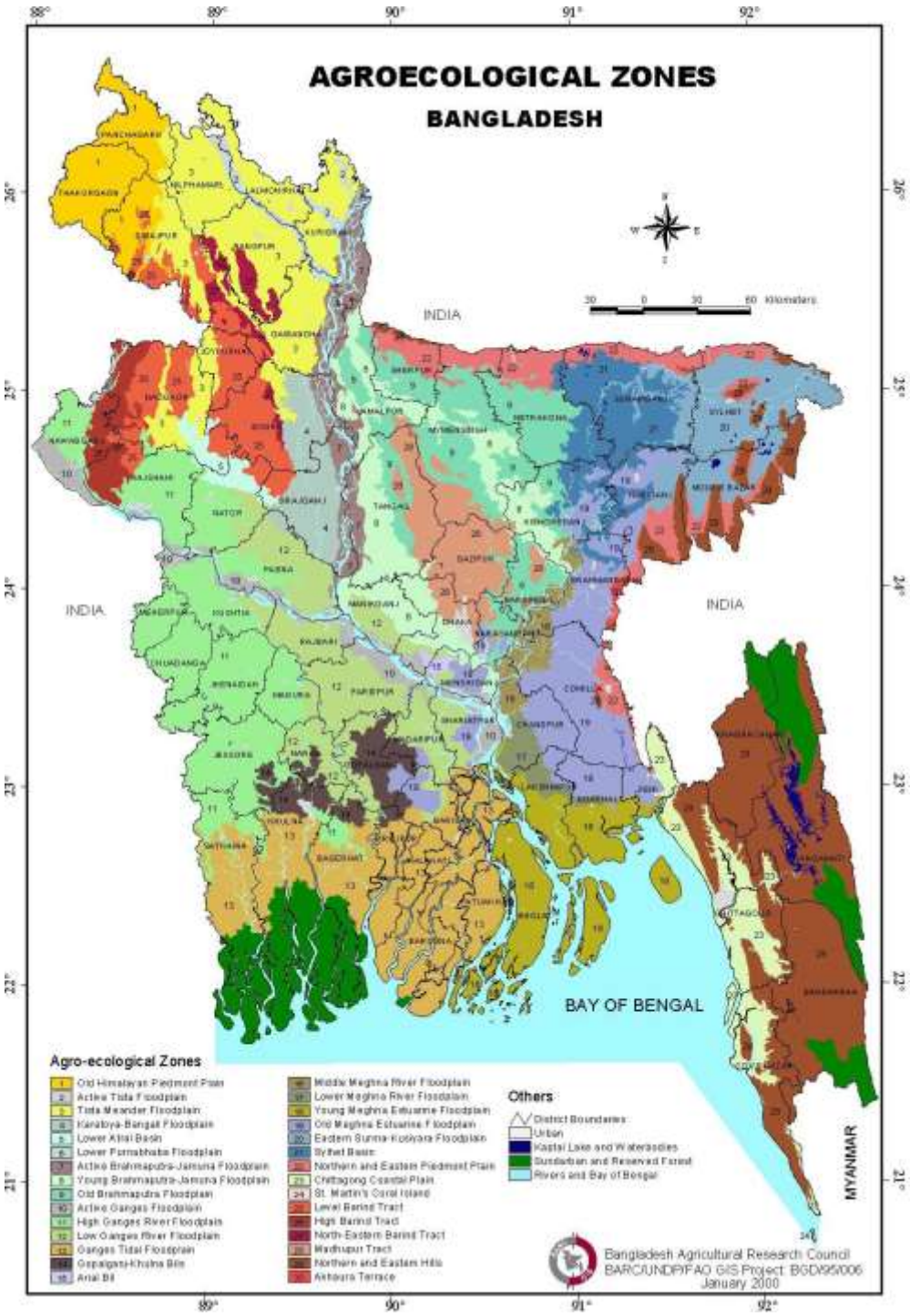
APPENDICES

Appendix I: Characteristics of soil of experimental is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka-1207

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Research Field laboratory, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	Medium hHigh land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

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



Source: Bangladesh Agricultural Research Council, Khamarbari, Dhaka.

Appendix III: Line graph showing the experimental sites average maximum and minimum temperature from November-17 to May-19 under study area.

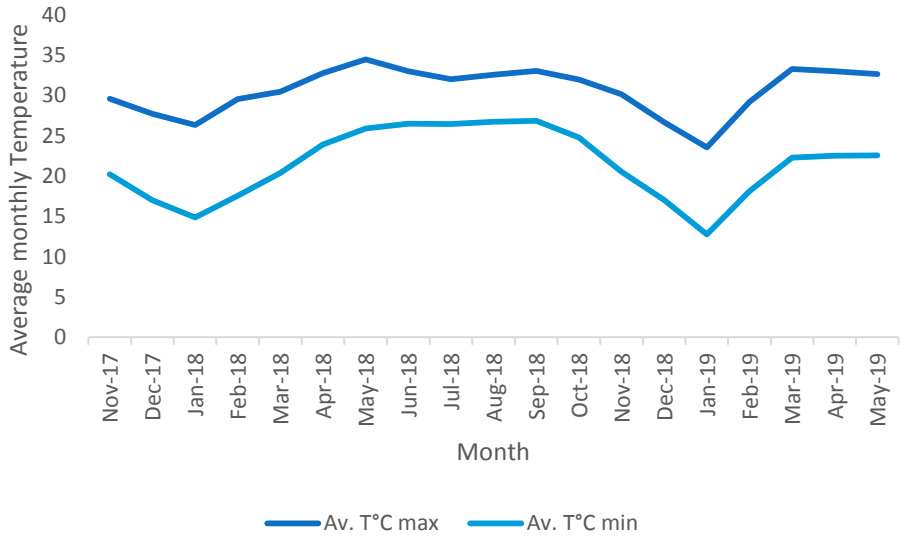


Fig: Line graph showing the experimental sites average maximum and minimum temperature from November-17 to May-19 under study area.

Appendix IV: Line graph showing the experimental sites average Relative Humidity (RH) from November-17 to May-19 under study area.

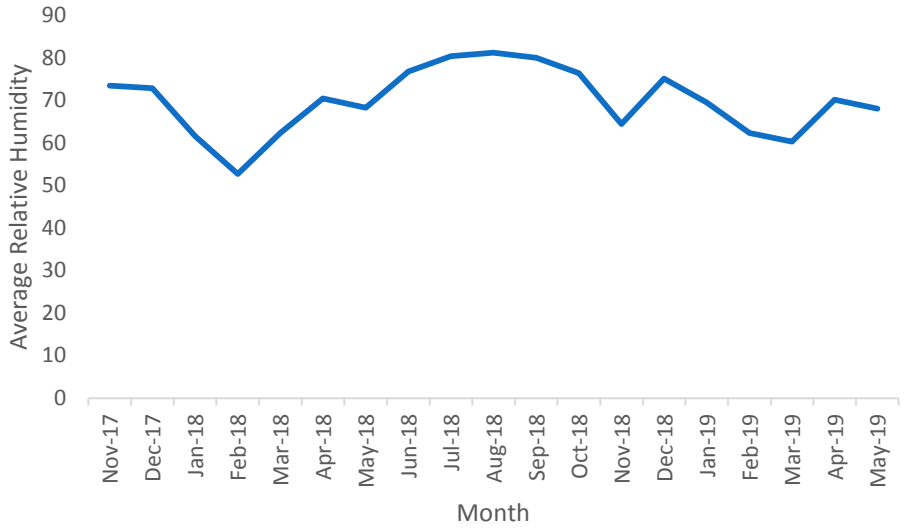


Fig: Line graph showing the experimental sites average Relative Humidity (RH) from November-17 to May-19 under study area.

Appendix V: Line graph showing the experimental sites average Total Rainfall (T Rain) from November-17 to May-19 under study area.

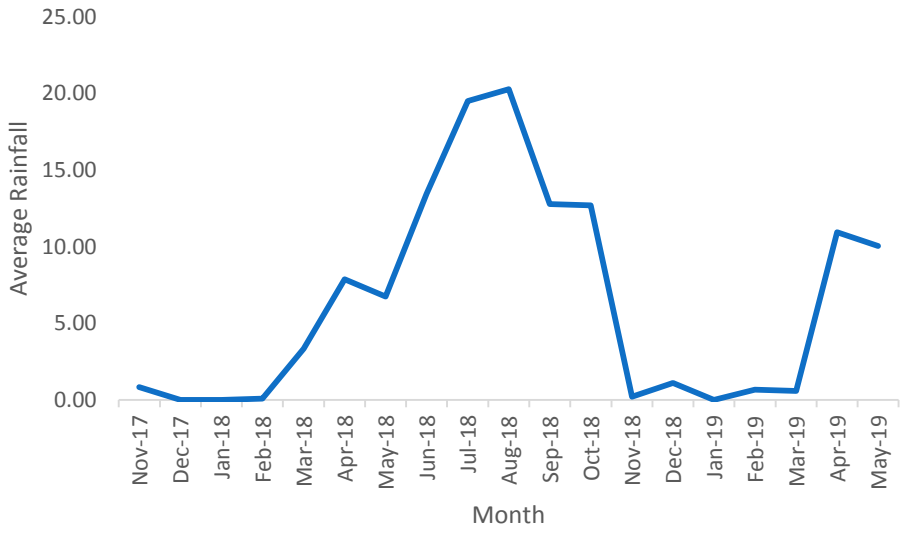


Fig: Line graph showing the experimental sites average Total Rainfall (T Rain) from November-17 to May-19 under study area

Appendix VI: Some photos of research plots:

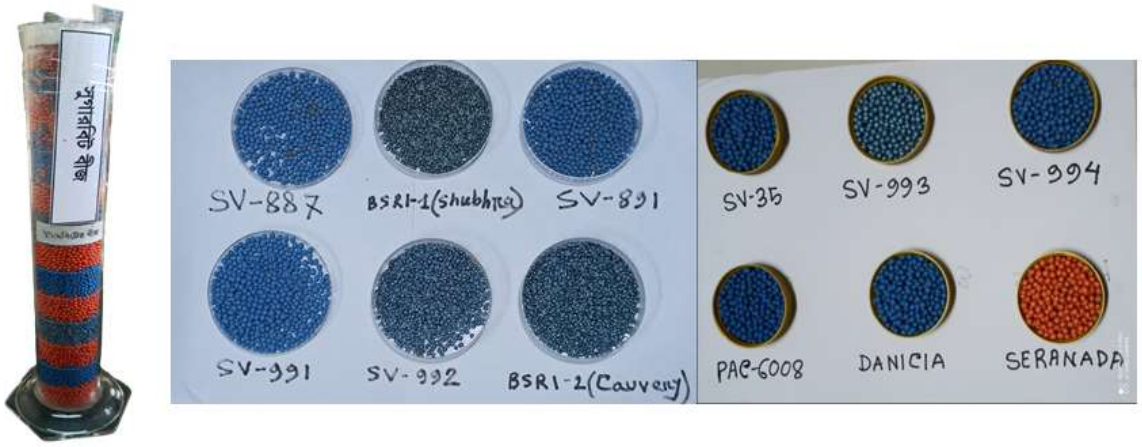


Plate 22: Tropical Sugarbeet seed

Plate 23: Automatic Polarimeter

(a) **(b)**

Plate 24. (a) and (b): Measurement of Brix (%) with Hand Refractometer at SAU experimental field.

Plate 25. Experiment of efficacy of botanicals and non-chemical approaches against the infestation of *Spodoptera litura* in tropical sugarbeet.

Plate 26. Spraying of insecticides in the sugarbeet field.

Plate 27. Spodo-Lure used in pheromone trap to control of *Spodoptera litura* .

Plate 28. Infested leaves of tropical sugarbeet caused by *Spdoptera litura* in the field.

Plate 29. An Infested leaf of tropical sugarbeet with egg mass and larvae of *Spdoptera litura*

Plate 30. Infested beet caused by larvae of *Spdoptera litura*