STUDY ON THE BIOLOGY AND DAMAGE ASSESSMENT OF SWEET POTATO WEEVIL, *CYLAS FORMICARIUS* IN THE LABORATORY

SAMEHA NOWSHIN

DEPARTMENT OF ENTOMOLOGY
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

JUNE, 2017

STUDY ON THE BIOLOGY AND DAMAGE ASSESSMENT OF SWEET POTATO WEEVIL, *CYLAS FORMICARIUS* IN THE LABORATORY

BY

SAMEHA NOWSHIN

REG. NO.: 16-07558

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfillment of the requirements
for the degree
of

MASTER OF SCIENCE (MS)

IN

ENTOMOLOGY

SEMESTER: JANUARY - JUNE, 2017

APPROVED BY:

…………………………………………………..	…………………………………………..
(Prof. Dr. Mohammed Ali)	**(Prof. Dr. Tahmina Akter)**
Supervisor	Co-Supervisor
Department of Entomology	Department of Entomology
SAU, Dhaka -1207	SAU, Dhaka-1207

…………………………………………………..

Dr. Mst. Nur Mahal Akter Banu
Chairman
Department of Entomology
&
Examination Committee

DEPARTMENT OF ENTOMOLOGY

Sher-e-Bangla Agricultural University

Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

This is to certify that the thesis entitled **'STUDY ON THE BIOLOGY AND DAMAGE ASSESSMENT OF SWEET POTATO WEEVIL, *CYLAS FORMICARIUS* IN THE LABORATORY'** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Science in Entomology** embodies the result of a piece of *bonafide* research work carried out by **SAMEHA NOWSHIN**, Registration number: **16-07558** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: June, 2017

Dhaka, Bangladesh

Prof. Dr. Mohammed Ali

Supervisor

&

Department of Entomology

Sher-e-Bangla Agricultural University

Dhaka-1207

ACKNOWLEDGEMENTS

The author first wants to articulate her enormous wisdom of kindness to the Almighty Allah for His never ending blessing, protection, regulation, perception and assent to successfully complete of research and prepare thesis.

The author likes to express her deepest sense of gratitude to her respected Supervisor **Prof. Dr. Mohammed Ali,** Department of Entomology, Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh for her scholastic guidance, support, encouragement, valuable suggestions and constructive criticism throughout the study period and gratuitous labor in conducting and successfully completing the research work and in the preparation of the manuscript writing including data analysis.

The author expresses the deepest sense of gratitude, sincere appreciation and heartfelt indebtedness to her respected Co-Supervisor **Prof. Dr. Tahmina Akter** Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka for her scholastic guidance, innovative suggestion, constant supervision and inspiration, valuable advice and helpful criticism in carrying out the research work and preparation of this manuscript.

The author express the sincere respect to the **Dr. Mst. Nur Mohal Akhter Banu,** Chairman, Examination Committee, Department of Entomology and all the teachers of the Sher-e-Bangla Agricultural University, Dhaka for providing the facilities to conduct the experiment and for their valuable advice and sympathetic consideration in connection with the study.

The author also expresses heartfelt thanks to all the teachers of the Department of Entomology, SAU, for their valuable suggestions, instructions, cordial help and encouragement during the period of the study.

The author expresses her sincere appreciation to her brother, sisters, relatives, well wishers and friends for their inspiration, help and encouragement throughout the study period.

The author

Date: June, 2017.

List of Abbreviation

Full word	Abbreviation
and others	*et al.*
Co-efficient of Variation	CV
Completely Randomized Design	CRD
Gram	g
Id est	i.e.,
Journal	*j*.
Least significant difference	LSD
Videlicet	Viz.,

STUDY ON THE BIOLOGY AND DAMAGE ASSESSMENT OF SWEET POTATO WEEVIL, *CYLAS FORMICARIUS* IN THE LABORATORY

BY

SAMEHA NOWSHIN

ABSTRACT

Consequently two experiments was conducted in laboratory of the Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from July to December, 2017 to damage assessment and study on the biology of sweet potato weevil *Cylas formicarius*. Different sweet potato such as BARI sweet potato 2 (kamala sunduri), BARI sweet potato 4 and local variety of sweet potato were used as experimental materials. An average incubation period was 4.6±6.188 days under room conditions on BARI sweet potato 2 in laboratory condition. Total 13.60±1.81 and 6.20±1.095 days were required for larval stage and pupal stage respectively. Adult longevity of sweet potato weevil, *C. formicarius* was 81.40±8.11 days. The length of egg was 0.68 ±0.083 mm and width 0.32±0.083 mm; 1 st , 2 nd and 3 rd instar larval length were 1.6 ±0.38 mm, 3.76 ±0.36 mm and 5.88 ±0.25 mm respectively and larval width were 0.28±0.03 mm, 0.52±0.07 mm and 0.81 ±0.04 mm respectively; Pupal length 6.2 ±0.36 mm and width 1.0 ±0.13 mm; the length of adult was 6.82 ±0.49 mm and width 1.8 ±0.15 mm. At the 1st and 2nd generations on weight basis, % infestation, the highest infestation was recorded from BARI sweet potato-2 (49.15% and 100.00%, respectively), which was statistically different from other sweet potatoes and followed by local variety of sweet potato (41.34 % and 75.05%), whereas, the lowest percent of infestation was recorded in BARI sweet potato 4 (23.37% and 51.68%, respectively). Present study showed positive correlation between weight loss and percent of infestation of all varieties of sweet potato; weight loss increased due to increase of percent of infestation of sweet potato.

Table of Content

List of Table

List of Plates

List of Figures

List of Appendix

CHAPTER I

INTRODUCTION

The sweet potato, *Ipomoea batatas* (L.) Lam. (Convolvulaceae), is one of the world's most important food crops, especially in developing countries, where it is a major source of sustenance and food security (Woolfe, 1992). Sweet potatoes pack a powerful nutritional punch. In one medium spud, there is over 400 percent of your daily vitamin A requirement, plus loads of fiber and potassium. They have more grams of natural sugars than regular potato but more overall nutrients with fewer calories. Sweet potatoes are a great source of beta-carotene, a powerful antioxidant that gives orange fruits and vegetables their vibrant color; beta-carotene is converted to vitamin A in the body. Consuming foods rich in beta-carotene may reduce the risk of developing certain types of cancer, offer protection against asthma and heart disease, and delay aging and body degeneration. Despite the crop's nutritional and economic importance, widespread sweet potato weevil infestation results in losses of millions of dollars annually (Jackai *et al.*, 2006).Sweet potato is currently ranked as the seventh most important crop in the world with a total production of 103 million tons in 2013 (FAO, 2015). It is produced largely in Asia (accounting for up to 76.1% of world production in 2013), followed by the African continent (19.5%) (FAO, 2015). The top five producers of sweet potato in 2014 were China, Nigeria, Uganda, Indonesia, and the United Republic of Tanzania (FAO, 2015). Sweet potato is one of the five most important crops in 40 developing countries besides rice, wheat, maize, and cassava (Elameen *et al.*, 2008).

Since weevils are widely dispersed in tropical regions of the world, their management is the key issue faced by farmers in major sweet potato producing countries. *Cylas formicarius* is an Asian species but is usually found throughout the tropical regions worldwide Sweet potato weevil is by far the most destructive pest of the sweet potato plant. The degree of infestation varies from region to region but weevils nevertheless cause severe damage to plantations. A research conducted by the Taiwan Agricultural Chemical and Toxic Substances Research Institute Council of Agriculture revealed that the damage caused by sweet potato weevil reduced sweet potato production in Taiwan by 1–5%, while the damage in extensive commercial produced fields was up to 18% (TACTRI/COA, 2014)

In China's Guangdong Province, yield generally shrunk by 5–20% and, in some cases, by up to 80%. In Vietnam, farm-level plantations losses were documented to suffer up to 40% of reduction in yield (Dinh *et al.,* 1995). Losses of 3–80% were recorded in Indonesia, throughout several locations and seasons (Bahagiawati *et al.,* 1989) and with higher damage observed during the dry season. In Malaysia, exact losses in the field were not recorded in recent years; the only documented figure was a 1970 study showing 80% yield loss or 4 tons/acre (Ho, 1970). In the Philippines, sweet potato yield was reduced by 50% due to *C. formicarius* infestation, while in Japan (Amami Islands), losses were recorded at 15% (Suenaga *et al.,* 1987). *Cylas spp*. was found to be the major pest in the tropical regions in Africa. Losses were recorded to be as much as 73% in Uganda (Smit, 1997); depending on the planting period and 15–20% in yield in Tanzania (Kapinga *et al.*, 1997). In other areas in the continent, losses have been shown to reach up to 100% (Fuglie, 2007).

Sweet potato weevil is the most serious pest of sweet potato around the world. It causes damage in the field, in storage, and is of quarantine significance. So it is important to identify the biology of weevil and calculate damage severity so that we can take proper measures to control as well as to reduce the economic loss.

OBJECTIVES OF THE STUDY

- ❖ To study the biology of sweet potato weevil, *C. formicarius*
- ❖ To determine the extent of damage and economic losses due to infestation of sweet potato weevil in sweet potato at storage condition
- ❖ To find out host predilection of sweet potato weevil in storage condition

CHAPTER II

REVIEW OF LITERATURE

Sweet potato (*Ipomoea batatas*), is a most versatile tropical tuber crop which used as a major source of staple food. The centre of origin of sweet potato is Central America, but the crop is widely grown in many tropical and subtropical countries. Sweet potato is ranked seventh in world staple food production (expressed on a dry matter basis), after wheat, maize, rice, potato, barley and cassava (Devi *et al.,* 2014). Sweet potato is currently ranked as the seventh most important crop in the world with a total production of 103 million tones in 2013; It is produced largely in Asia (accounting for up to 76.1% of world production in 2013), followed by the African continent (19.5%) and the top five producers of sweet potato in 2014 were China, Nigeria, Uganda, Indonesia, and the United Republic of Tanzania (FAOSTAT, 2015).

In Bangladesh sweet potato is the 4th most important source of carbohydrate after rice, wheat and potato. Sweet potato plays a significant role in increasing food security and income for the poor farmers of Bangladesh (Ahmed *et al*., 2015).

The area and production under sweet potato was 24,567 hectare and 297,539 tons, respectively in Bangladesh during the year 2011 (FAOSTAT, 2011). Despite the crop's economic importance, widespread sweet potato weevil infestation results in losses of millions of dollars annually. It attacks sweet potato both in the field and during storage. (Jackai *et al.*, 2006).

The weevil is monophagous to the extent that significant feeding, growth and reproduction only occur on *Ipomoea* spp. in the Convolvulaceae, *I. batatas* its preferred host. The damage is caused by feeding and egg laying punctures of the adults but is mostly caused by the feeding of larvae in the roots and tubers. Slight feeding may cause the potato to be unfit for human consumption because of the presence of larvae and the bitter flavor. It does feed on the above parts of the plant but this damage is insignificant as compared to the feeding in the root (Burns, 1999).

Sweet potato weevil is a universal pest and causing extensive damage. The low yield 10-15 tones ha-1 in India is attributed to damage caused by the sweet potato weevil *C. formicarius* Fab. In India, a yield loss to the extent of 60 to 100 per cent was often noticed (Pillai and Palaniswami, 1984).

Sweet potato weevils, *Cylas spp*., are the most destructive and widely distributed pest of sweet potato [*Ipomoea batatas* (L) Lam] in tropical and subtropical areas of the world. Larvae of this pest tunnel through roots which results in major damage and economic yield loss (Chalfant *et al.*, 1990).

A conservative estimate of the loss due to these insects would be 10 to 20 percent of the crop. Their damage is not restricted to the field but may also occur during storage. The damage is caused by the feeding of adult and larvae on the roots and stems of the plant. The feeding of the larvae causes the greater economic damage. Their tunneling through the main stem often causes it to become greatly enlarged and cracked. This condition will, in cases of severe injury, interfere with the normal physiological processes. Of more direct importance is the injury to the edible root. The feeding tunnels are filled with frass. This makes the potatoes unmarketable, and the resulting bitter taste often makes the potatoes unpalatable even to livestock (Shermar and Tamashi, 1954).

2.1 Sweet Potato Weevil Infestation by Regions

Sweet potato weevil is by far the most destructive pest of the sweet potato plant. The degree of infestation varies from region to region but weevils nevertheless cause severe damage to plantations. A research conducted by the Taiwan Agricultural Chemical and Toxic Substances Research Institute Council of Agriculture revealed that the damage caused by sweet potato weevil reduced sweet potato production in Taiwan by 1–5%, while the damage in extensive commercial produced fields was up to 18% (TACTRI/COA, 2014).

In China’s Guangdong Province, yield generally shrunk by 5–20% and, in some cases, by up to 80% (Anonymous, 1984).

In Vietnam, farm-level plantations losses were documented to suffer up to 40% of reduction in yield (Dinh *et al.*, 1995). Losses of 3–80% were recorded in Indonesia, throughout several locations and seasons (Bahagiawati, 1989) and with higher damage observed during the dry season (Braun and van de Fliert, 1999).

In Malaysia, exact losses in the field were not recorded in recent years; the only documented figure was a 1970 study showing 80% yield loss or 4 tons/acre (Ho, 1970). In the Philippines, sweet potato yield was reduced by 50% due to *C. formicarius* infestation (Gapasin, 1989), while in Japan (Amami Islands), losses were recorded at 15% (Suenaga *et al.*, 1987).

Cylas spp. were found to be the major pest in the tropical regions in Africa. Losses were recorded to be as much as 73% in Uganda (Smit, 1997) depending on the planting period and 15–20% in yield in Tanzania (Kapinga *et al.*, 1997).

In other areas in the continent, losses have been shown to reach up to 100% (Fuglie, 2007 and Nderitu *et al.*, 2009).

In the United States, the southern states of Alabama, Louisiana, Mississippi, and North Carolina produce 75% of sweet potato supply (USEPA, 2003). While the main pests affecting sweet potato plantations in these regions include sweet potato weevils, wireworms, white grubs, sweet potato flea beetle, cucumber beetle, white fringed beetle, and sugarcane beetle, weevils cause the worst damage to this crop (USEPA, 2003).

Jansson *et al.*, 1987 reported that, in Southern Florida, up to 80% (average 69%) of losses in sweet potato yields have been reported, mainly contributed by the death of infested plants.

Due to the severity of this problem, several workshops were conducted by universities in this state to bring together all parties involved to develop plans for pest management in sweet potato production (USEPA, 2003).

According to Maynard, 1999, through these activities, IPM strategies were implemented (such as pheromones trap and usage of selected approved pesticides); farmers were also given information about planting strategies (bedding and soil preparation) to minimize infestation and the introduction of sweet potato cultivar with higher resistance to weevils (such as Regal).

In the Dominican Republic, sweet potato farm-level losses due to weevil infestation were estimated at 39% (Swindale, 1992). Weevil is also found in all provinces of Cuba where sweet potato plantations are located and, in the absence of adequate control, losses have been shown to reach up to 45% (Alcazar *et al.*, 1997).

2.2 Origin and distribution of sweet potato weevil

The sweet potato weevil was first described in 1792-94 by Fabricius (Fabricius, 1792-94) who called it *Brentus formicarius*, from specimens evidently from Trenquebar, India. Later he Classified it as *Attelabus formicarius*, but after a time he gave It its original designation of *Brentus onnicarius.*

This classification remained undisturbed until after the erection of the genus *Cylas*, when Olivier (Olivier, 1807) placed the species in this genus. Summers (Summers, 1875) in 1875 described this weevil as *Otidocephalus elegantulus*.

Le Conte and Horn (Le Conte and Horn, 1876) stated that this is synonymous with *Cylas formicarius*. Pierce (Pierce, 1918) in 1918 published a detailed description and key for separating pecies of *Cylas*.

Specialists in the United States National Museum in 1941 decided that the correct designation for this insect should be *Cylas formicarius* sub-species *elegantulus* Sum., and this name still applies. Newell (Newell, 1917) referred to the insect under the common name "sweet potato root weevil."Comstock (Co.MSTocK, 1879), Hinds (Hinds, 1918) and Conradi (CoNRADi, 1907) called it" the sweet potato root borer, "but" sweet potato weevil" is now generally accepted as the common name.

Since weevils are widely dispersed in tropical regions of the world, their management is the key issue faced by farmers in major sweet potato producing countries. The four main species of weevils that cause the most harm to sweet potato plantation are *Euscepespost fasciatus* (Fairmaire), *Cylas formicarius* (Fabricius), *Cylas puncticollis* (Boheman), and *Cylas brunneus* (Fabricius) (Chalfant *et al.*, 1990) (Korada *et al.*, 2000). *Euscepespost fasciatus* is a South American species that is more prevalent in Central and South America. *Cylas formicarius* is an Asian species but is usually found throughout the tropical regions worldwide including North America, the Caribbean, Europe, Africa, Asia, and Oceania. *Cylas brunneus* and *Cylas puncticollis* are African species and are restricted to Africa. There are other species of sweet potato weevils in the tropical regions in Africa, for example, the rough sweet potato weevil (*Blosyrus* spp.) and striped sweet potato weevil (*Alcidodes dentipes* and *Alcidodes erroneous*), but their damage to sweet potato cultivation is not as severe as the main species (*Cylas* spp.) (Ames *et al.*, 1996).

2.3 Systematic position

Kingdom: Metazoa
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Coleoptera
Family: Apionidae
Genus: Cylas
Species: *Cylas formicarius*

2.4 Nutrients in sweet potato

Sweet potato contains approximately 20% starch and 5% simple sugar, and is considered a high energy food. In some parts of the world sweet potato is the staple crop. It also contains large amounts of vitamin C, ranging from 20 to 30 mg per 100 grams. Like potatoes, sweet potatoes contain vitamin A-carotenoids in amounts sufficient for good nutrition if eaten in a large quantity. The carotene content is about 0-8000 IU/100 gm sweet potato. Vitamin 131 (thiamin) is also present in substantial amounts 0.8-1.0 mg/1000 Kcal, which is about twice the human requirement (Huang, 1982). Among the minerals potassium is dominant. Iron content is sufficient (0.8 mg/100 gin). The protein content of sweet potato is generally low contributing 4-6% of the total calories. It is reasonable to assume that if sweet potato comprises more than 90% of the total caloric intake in any diet, protein deficiency is likely to occur (Huang, 1982). Therefore, a diet based on sweet potato should be supplemented with some protein-rich food.

2.5 Sweet potato in Bangladesh

In Bangladesh, sweet potato covers an area of 30.4 thousand hectare with a production of 297.539 thousand metric tons indicating a national yield of 9.8 t/ha in 2010-11. Some 14 wild species available i.e. *I. imolucrata, I. learii, I. nil, I. purpurea, I. rubens, I. aspera, I. longiflora, I. illustris, I. pe-niculata, I. pescaprae, I. reptans, I. salicifolia, I. obscura, I. sepinria,* etc. in Bangladesh. BARI has also developed 13 high yielding varieties of sweet potato for commercial cultivation. Among them, 4 varieties are clonal hybrid. The centre has collected more than 500 sweet potato germplasm from home and abroad. At present, 255 germplasm of sweet potato are being maintained in the field gene bank. The exotic sources of sweet potato were USA, Philippines, Taiwan, Puerto Rico, Srilanka, Japan, India, IITA and CIP, Peru (Kawochar *et al*., 2014).

Out of 13 varieties, 4 varieties are clonal hybrid, namely BARI SP-4, BARI SP-5, BARI SP-10 and BARI SP-11 developed from own crossing program and rest 9 varieties were introduced from exotic or local source. At present, BARI SP-2 (Kamala sunduri), BARI SP-4, BARI SP-8 and BARI SP-9 are the popular varieties throughout the country. BARI SP-1 (Tripti) is light yellow skin with light orange flesh which was introduced from Philipine. BARI SP-2 (Kamala sunduri) is a deep orange fleshed variety with 7500 IU/100 g edible flesh which was introduced from Taiwan. Most of the varieties of sweet potato are orange fleshed which is rich in Beta carotene except BARI SP-3 (Daulat-puri) is white fleshed and devoid of carotene but high dry matter of 33 %. BARI SP-4 and BARI SP-5 is highly accepted to the farmers for its attractive flesh and skin color. BARI SP-6 and BARI

SP-7 was introduced from CIP, Peru and adapted as saline tolerant at the costal belt. BARI SP-8 and 9 also introduced from CIP, Peru and adapted as high yielding variety over the country. BARI SP-10 and BARI SP-11 are clonal hybrid developed by open cross and released in 2013 as high dry mater containing variety. BARI SP-12 and BARI SP-13 is introduced variety from CIP, Peru released in 2013 as high beta carotene containing variety with deep orange flesh. Sweet potato is cultivated all over the Bangladesh but it is more concentrated in Bogra, Jamalpur, Rangpur, Kurigram and Lalmonirhat districts (Kawochar *et al.*, 2014).

2.6 Mode of action of Sweet Potato Weevil

Although different subspecies of sweet potato weevils can be found in different geographical locations, their modes of action remain the same (Capinera, 2001). Sweet potato weevils generally cause serious damage to all parts of sweet potato plant throughout their life cycle, from egg to adult. When laying eggs, female weevils excavate cavities and create egg-laying punctures in the roots. The eggs are laid below the surface of the roots and covered with dark color excrement from the female adults (Capinera, 2001). As a result of the unsightly punctures, the appeal of the roots and market price of sweet potato become greatly reduced, resulting in major economic losses.

Hatching will generally occur in a week after oviposition by females. Hatched larvae will start making tunnels inside tubers and feed inside galleries (Onwueme and Charles, 1994). The tunnels inside the tubers of sweet potatoes will be filled with excrement from the larvae. As the larvae feed, the sweet potato will impart a bitter flavor and terpeneodour, making it unsuitable for the consumption of human or livestock. The presence of terpenoid reduces the marketable yield and root quality of sweet potatoes (Uritaini *et al.*, 1975). Mining of sweet potato tubers by larvae is the principal cause of sweet potato damage. The tuber becomes spongy in appearance, riddled with cavities, and dark in color (Uritaini *et al.*, 1975). Besides that, larvae also mine into the vines of sweet potato, causing it to darken, crack, and collapse. Apparent symptoms of weevils infestation will be yellowing of the vines but this usually only occur after heavy infestation (Uritaini *et al.*, 1975).

2.7 Factors Influencing Sweet Potato Weevil Infestation

2.7.1. Physical Attributes of Sweet Potato

Host plant resistance plays an important role in the management of serious insect pests (Rao, 2005). Apart from the nutritional quality of its tuber, the physical attributes of sweet potato, including its flesh color, neck length, shape, thickness, and skin color, influence the infestation by sweet potato weevils. Oval- and round-shape sweet potato tubers were more severely infested by sweet potato weevils compared to elongate, spindle, and long stalked ones. Besides, cultivars with pink and red colored tubers as well as lobed leaves and thin foliage were considered less susceptible compared to brown and white colored tubers (Teli and Salunkhe, 1996).

The level of infestation in the different sweet potato genotypes was reported to be related to the concentration of kairomones in the periderm of the tubers. For example, boehmeryl acetate, a kairomone identified in sweet potato tubers surface, acts as an ovipositional stimulant for female weevils (Son *et al.*, 1990). This finding was supported by Nottingham et al. (Nottingham *et al*, 1989) who discovered triterpenol acetate on the root surface of the genotype “Centennial” which has shown similar function to other kairomones. This suggests that selection of sweet potato genotypes with increased deterrents or decreased concentration of kairomones such as boehmeryl acetate and triterpenol acetate may significantly facilitate sweet potato resistance to weevils (Rao, 2005). Therefore, the selection of sweet potato variety is important for the control of sweet potato weevils.

Deep-rooting and early maturing varieties (90 to 120 days) are about four times less susceptible to infestation than shallow-rooting and late maturing varieties (180 days or more). As a result, both deep storage roots and early maturing varieties tend to reduce the severity of weevil damage (Lima and Morales, 1992). More than 95% of oviposition by female weevils happens in the first 35 cm of vines and planting of infested cuttings is one of the ways of distributing sweet potato weevils (Lima and Morales, 1992). Therefore, treatment of infested stem cuttings with insecticides or *Beauveria bassiana* is currently being practiced to reduce weevil infestation.

2.7.2. Age of Stem Cutting

Female weevils tend to lay eggs in the older portions of vines, especially when they cannot access the roots or the storage roots are absent. Since planting of infested cuttings or vines will spread weevil infestation, weevil-free cuttings of sweet potato vines produced by dipping in an insecticide solution are recommended (Smith and Odongo, 2002). Older portions of cuttings are usually severely infested with weevils, while younger cuttings are rarely infested with weevils. This notion is supported by a field study, which showed increase in number of weevils in vines in increased vine age (AVRDC, 1990).

2.7.3. Altitude and Season

Weevil infestation has a strong relationship with the location altitude and planting season of sweet potato. Several studies have concluded that higher temperature may increase the growth rate of insect's population as well as the risk and severity of the outbreaks (Gomi *et al*., 2007) (Ladányi and Hufnagel, 2006). In Kerala, India, tuber damage by weevil infestation was observed to be less serious in lowland (up to 22%) compared to upland (4 to 50%) (Rajamma, 1983). On the other hand, a study in Kabale District, Uganda, reported higher number of *Cylas spp*. infestation at lowland (up to 1814 meters above sea level) (77%) compared to the number of *Cylas spp*. at higher altitude (1992–2438 meters above sea level) (23%) (Okonya and Kroschel, 2013). The rate of infestation in this case may be also affected by other reasons such as method used in planting, sanitation level in that area, and the variety of sweet potato planted.

According to Bhat (Bhat, 1996), the incidence of weevil infestation was higher when planting in the period from August to November (87.4%) compared to the planting in the period from June to July (10.9%). A study conducted in India showed that tuber damage was higher (71%) during summer season (February–May) compared to monsoon season

(June–September) (45%) (Rajamma, 1983). Thus, weevil infestation can be reduced by proper planning of planting and harvesting time as well as the planting location.

In addition, sweet potato weevil relies strongly on cracks in dry soil to reach the storage roots, as they cannot dig. Hence, weevils cannot reach roots which are well buried under the soil. The enlargement of roots near the soil surface and the stress from soil moisture can increase the chances of producing cracks and exposure of roots to the weevils. The incidence of damage caused by sweet potato weevils was observed to be lesser during wet season compared to dry season as the absence of cracks hinders weevils from accessing the roots (Hahn and Leuschner, 1982; Rajamma and Padmaja, 1981 and Sutherland, 1986).

2.8 Life cycle of sweet potato weevil

A complete life cycle requires one to two months, with 35 to 40 days being common during the summer months. The generations are indistinct, and the number of generations occurring annually is estimated to be five in Texas, and at least eight in Louisiana. Adults do not undergo a period of diapause in the winter, but seek shelter and remain inactive until the weather is favorable. All stages can be found throughout the year if suitable host material is available (Sherman and Tamashiro, 1954). .

Sutherland, 1986 reported that hot, dry weather favors weevil development. At optimal temperatures of 27-30^{o}C, *C. formicarius* completes development (from egg to adult) in about 33 days. Adult longevity is about 75-105 days and females lay between 100 and 250 eggs in this period. At suboptimal temperatures, development takes longer.

The life cycle occurs entirely on the host plant and a full cycle can be completed in as little as 33 days under warm to hot conditions but this period is greatly extended during cold weather. Eggs are laid singly in pits produced by the female in the vines near the crown above the soil or in exposed roots. As the top portion of roots increase in size they become exposed due to soil erosion or soil cracking, and therefore become a preferred egg laying site. Under warm spring and summer conditions the small larvae hatch in about 8 days and tunnel within the host tissue. They develop through three stages prior to pupation (Sherman and Tamashiro, 1954).

The larval period is variable depending on temperature ranging from 10-25 days. Pupation occurs within the larval burrows and lasts for about 8 days. Adults are relatively long lived and females start laying eggs about a week after emergence and can continue to lay eggs for a period of three or more months. Adult weevils feed on host leaves, leaf petioles and stems. The damage it causes on aerial parts is considered to have minor economic importance compared to the damage inflicted by the larvae feeding on crowns and more importantly the marketable roots. Even minor damage to the roots makes them unfit for human consumption due to release of bitter and unpleasant terpene flavors, caused by weevil feeding and hence, culling of even slightly infested roots at harvest or during packing is very important and results in reduced packing throughput. In Australia, direct average crop losses from discarded roots has been estimated at between 5 and 15% of production but total losses have been reported in some crops where the level of damage makes harvest uneconomic. Reduced root yield due to crown and stem damage could not be demonstrated by Takelar (1982) but our results, using the susceptible cultivar Centennial, have shown that even moderate levels of damage to the crown resulted in a reduction in total root weight.

Devi *et al.*, 2014 reported that, the life stages of *Cylas formicarius* in sweet potato tubers were assessed during first and second generations. In first generation, the highest egg period was recorded in Co-3 (White) (5.50 days). The lowest larval period was recorded in Kanjangad (24.16 days) while highest pupal period was recorded in Kanaka (Red) (7.56 days) and the total life cycle period in days was highest in Co-3 (White) (42.49 days) whereas the lowest mean life cycle period was recorded in Kanjangad (Red) (33.59 days). In the second generation, the highest egg period was recorded in Co-3 (White) (5.80 days), lowest larval period was recorded in Villupuram local (Red) (25.34 days). The highest pupal period was recorded in Kanaka (Red) (7.89 days). The highest total life cycle period was recorded in Co-3 (White) (43.67 days) and lowest total life cycle period was recorded in Villupuram local (Red) (35.40 days).

Egg: Eggs are deposited in small cavities created by the female with her mouthparts in the sweet potato root. The female deposits a single egg at a time, and seals the egg within the oviposition cavity with a plug of fecal material, making it difficult to observe the egg. Most eggs tend to be deposited near the juncture of the stem and root (tuber). Sometimes the adult will crawl down cracks in the soil to access tubers for oviposition, in preference to depositing eggs in stem tissue. The egg is oval in shape and creamy white in color. The weevil eggs are white or pale yellow and broadly oval (Sorensen, 2009).

Its size is reported to be about 0.7 mm in length and 0.5 mm in width. Duration of the egg stage varies from about five to six days during the summer to about 11 to 12 days during colder weather. Females apparently produce two to four eggs per day, or 75 to 90 eggs during their life span of about 30 days. Under laboratory conditions, however, mean fecundity of 122 and 50 to 250 eggs per female has been reported (Cockerham *et al*, 1954)

Larva: When the egg hatches the larva usually burrows directly into the tuber or stem of the plant. Those hatching in the stem usually burrow down into the tuber. The larvae are dirty white with a C-shaped body and a pale brown head (Sorensen, 2009).

The larva is legless, white in color, and displays three instars. The mean head capsule widths of the instars are 0.29 to 0.32 mm, 0.43 to 0.49 mm, and 0.75 to 0.78 mm for instars 1 to 3, respectively. Duration of each instar is 8 to 16, 12 to 21, and 35 to 56 days, respectively. Temperature is the principal factor affecting larval development rate, with larval development (not including the prepupal period) occurring in about 10 and 35 days at 30^{o} and 24^{o} C, respectively. The larva creates winding tunnels packed with fecal material as it feeds and grows (Cockerham *et al*, 1954).

The newly hatched larva is somewhat larger than the egg. The full-grown apodous larva is 7.5-8.0 mm long and 1.8-2.0 mm wide. The head is comparatively large, measuring approximately one third of the body length and half the width. The color is white or pale-yellow. The head and mandibles are chitinized yellow to brown; mandibles are almost black. The body is slightly curved (Kemner, 1924).

Gonzals (1925) in the Philippines claimed that *Cylas formicarius* had five instars. He based his findings on 12 larvae which he reared individually on thin pieces of sweet potato roots. He considered the presences of the head capsule as the usual criterion of molting. However, at times, he could not find the capsule; but if the head was white, he considered that molting had occurred. According to his data, the width of the head of the five instars was as follows: 0.25, 0.42, 0.61, 0.64 and 0.66 mm. Fukuda (1933) in Formosa claimed that *Cylas formicarius* had four instars, but he presented neither physical measurements nor information how this was determined.

Pupa: The mature larva creates a small pupal chamber in the tuber or stem. The pupa is similar to the adult in appearance, although the head and elytra are bent ventrally. The pupa measures about 6.5 mm in length. Initially the pupa is white, but with time this stage becomes grayish in color with darker eyes and legs. Duration of the pupal stage averages 7 to 10 days, but in cool weather it may be extended to up to 28 days (Cockerham *et al.*, 1954).

The full-grown larva turns into a pupa in an enlarged area of the feeding tunnel. The pupa is whitish, 6.0-6.5 mm long. The long snout is bent towards the ventral side (Kemner, 1924).

Adult: Normally the adult emerges from the pupation site by chewing a hole through the exterior of the plant tissue, but sometimes it remains for a considerable period and feeds within the tuber. The adult is striking in form and color. The body, legs, and head are long and thin, giving it an ant-like appearance (Cockerham *et al.*, 1954).

The weevil has a narrow head and thorax. The head and abdomen are dark metallic blue, and the thorax and legs are reddish orange. The antennae are reddish brown and are clubbed on the end. The adult is about 0.25 inch long. The weevils spends its entire life cycle on the host plant, and both larval and adult stages damage the tubers and vines (Sorensen, 2009).

The length of the adult female is between 4.80 and 6.70 mm; the males are slightly larger, between 5.00 and 6.75 mm. The basic color of the insect is red but this color is usually masked, because the head is black, the elytra blue or bluish-green, sometimes black, and shining, the back of the thorax and sternites are usually dark bluish-green. The legs are red with a broad dark ring around the tibiae which sometimes may not be very distinct in general specimens. The head extends into a long snout which is either uniformly wide or slightly wider at the front (The snout or rostrum is that part of the head which is anterior to the eyes.) Antennae have 10 segments. In males the distal segment of antenna is a narrow club, uniformly wide, sausage-shaped, densely pubescent and more than twice as long as the flagellum. The distal antennal segment in the female is egg-shaped, only two-thirds the length of the flagellum (Kemner, 1924).

According to Capinera (1998), the body, legs, and head are long and thin, giving it an ant-like appearance. The head is black, the antennae, thorax and legs orange to reddish brown, and the abdomen and elytra are metallic blue. The snout is slightly curved and about as long as the thorax; the antennae are attached at about the midpoint on the snout. The beetle appears smooth and shiny, but close examination shows a layer of short hairs. The adult measures 5.5 to 8.0 mm in length. Under laboratory conditions at 15 C, adults can live over 200 days if provided with food and about 30 days if starved. In contrast, their longevity decreases to about three months if held at 30o C with food, and eight days without food. Adults are secretive; often feeding on the lower surface of leaves, and are not readily noticed. The adult is quick to feign death if disturbed. Adults can fly, but seem to do so rarely and in short, low flights. However, because they are active mostly at night, their dispersive abilities are probably underestimated. Females feed for a day or more before becoming sexually active, but commence oviposition shortly after mating; the average pre-oviposition period is seven days. A sex pheromone produced by females has been identified and synthesized.

Ames and braun (1996) reported that adults may be conveniently sexed by the shape of the distal antennal segment, which is filiform (thread like, cylindrical) in males and club like females. The males have larger eye facets than the females. At optimal temperatures of 27-30^{o}C, *Cylas formicarius* complete development (from egg to egg) in about 33 days. Adult longevity is 2 ½ to 3 ½ months and females lay between 100 and 250 eggs in this period.

2.9 Management of sweet potato weevil

2.9.1. Sampling: Over 90 percent of larvae are found in the upper 15 cm of the tubers and basal 10 cm of the vine. Early in the season larvae are found about equally in the vine and tuber, but later in the season most occur in the tubers. Distribution of sweet potato weevil in fields is aggregated. Pheromone traps show great promise for monitoring of adult population density. Weevils respond to low concentrations of pheromone, and apparently will move up to 280 m to a pheromone source. The sex pheromone also shows great potential for mating disruption and mass trapping (Capinera, 1998).

2.9.2 Insecticides: Planting time applications of insecticides are commonly made to the soil to prevent injury to the slips or cuttings. Either granular or liquid formulations are used, and systemic insecticides are preferred. Post plant applications are sometimes made to the foliage for adult control, especially if fields are likely to be invaded from adjacent areas, but if systemic insecticide is applied some suppression of larvae developing in the vine may also occur. Due to the long duration of the plant growth period, it is not uncommon for preplant or planting time applications to be followed by one or more insecticide applications to the plant or soil at mid season. Insecticides are also applied to tubers being placed into storage to prevent reinfestation and inoculation of nearby fields (Capinera, 1998).

2.9.3. Cultural practices: Cultural practices are sometimes recommended to alleviate weevil problem. Isolation is frequently recommended, and it is advisable to locate new fields away from previous crops and distant from sweet potato storage facilities, because both can be a source of new infestations. However, despite the infrequency of flight by adults, dispersal can occur over considerable distances. Dispersal rates of 150 m per day have been observed, with dispersal more rapid in the absence of suitable hosts.

Sanitation is particularly important for weevil population management. Discarded tubers and unharvested tubers can support large population, and every effort should be made to remove such host material. Related to this, of course, is the destruction of alternate hosts; control of Ipomoea weeds is recommended (Capinera, 1998).

2.9.4. Biological control: Entomopathogenic nematodes seem to be the organisms with the greatest potential for practical biological suppression of sweet potato weevil. Several strains of *Steinernema carpocapsae* (Nematoda: Steinernematidae) and *Heterorhabditis bacteriophora* (Nematoda: Heterorhabditidae) penetrate the soil and tubers, killing weevil larvae. At least in the soils of southern Florida, the infective nematodes are persistent, remaining active for up to four months. In some cases nematodes are more effective than insecticides at reducing damage (Capinera, 1998).

2.9.5. Other methods: Other methods of suppression are sometimes used, especially for postharvest treatment of tubers. Postharvest treatment not only prevents damage in storage, but allows shipment of tubers to areas where sweet potato weevil is not found but might survive. Traditionally, postharvest treatment has been accomplished with chemical fumigants, but they have fallen from favor. Irradiation is potentially effective, although older stages of insects are less susceptible to destruction. Storage in controlled atmospheres, principally low oxygen and high carbon dioxide, is very effective for destruction of weevils, but requires good storage conditions (Capinera, 1998).

CHAPTER III

MATERIALS AND METHODS

Experiments were conducted to estimate the duration of the developing stages of sweet potato weevil, *C. formicarius* Fabr. during the growing season of sweet potato which extended from July 2016 to June 2017. The experiments were carried out in room temperature and relative humidity.

Experiment 1: Study on the biology of Sweet potato weevil, *C. formicarius* in the laboratory

The study was conducted in the laboratory of the Department of Entomology of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from July 2017 to December 2017. The biology of *C. formicarius* was studied on sweet potato, which was collected from local market of Dhaka.

3.1.1 Collection and rearing of sweet potato weevil: Adults of sweet potato weevil were collected along with the infested sweet potato from the laboratory of Entomology Department, Sher-e-Bangla Agricultural University, Dhaka and stored them in a rearing box for rearing sweet potato weevil.

3.1.2 Stock culture of Sweet potato weevil, *Cylas formicarius*

The collected insects were maintained in the laboratory of Entomology Department, Sher-e-Bangla Agricultural University, Dhaka. Different stages of *C. formicarius* were reared in rearing cage with sweet potato (Plate 01) in the laboratory. Adult were sort out from infested sweet potato and then transferred to another rearing cage for the study of biology of *C. formicarius.*

Plate 01: Stock culture of *C. formicarius* in with sweet potato in rearing cage

3.1.3. Biology of Sweet potato weevil, *C. formicarius*

This laboratory work was started by establishing a laboratory insect culture. Some storage tubers were put in plastic jar covered by mesh net till adults emerged. Others were cut into small pieces using a sharp knife, and larvae and pupae picked from them were reared in Petri-dishes (Plate 2), in clean sweet potato slices, 3-5mm thick. After a suitable stock of adult insects was available, adults were sexed by the shape of the length, the length of the adult female is between 4.80 and 6.70 mm and tapering abdomen; the males are slightly larger, between 5.00 and 6.82 mm and bearing narrow abdomen then female. Then five pair of insects (a male + a female) was put in separate plastic jar closed with mesh net (Plate 3) and a leaf of sweet potato and a sound, medium to small size storage sweet potato were supplied every 48 hrs. Five plastic jars each containing five pair of insects were used during this study. Every 2 (two) days interval; storage sweet potato were removed from the jars and divided into two equal groups, each one was put in a separate plastic jar and labeled. One plastic jar was put under room ambient conditions. This process started on July 2017 and continued to the end of the month December.

.

Plate 2: Petri-dish and sweet potato slice where immature stages reared under laboratory conditions

Plate 3: Five pairs of sweet potato weevil, *C. formicarius* was put in separate plastic jar closed with mesh net in rearing

Daily each plastic jar was examined to see if there are any eggs hatched. Three days after hatching onwards from each plastic jar two storage tubers were cut into pieces with a sharp knife. Larvae which were found were transferred to Petri-dishes, under room temperature and humidity conditions. The Petri-dishes were labeled and kept under daily observation. Records were taken for the developing stages until emergence. Sweet potato slices were changed daily (using healthy fresh storage Sweet potato, knives, camel's hair brush, forceps, needles and soap water to clean the knives) during the rearing of larval stage and as was needed during the pupal stage. From every plastic jar two or more storage sweet potato remained undisturbed until adults emerged.

3.1.4. Study morphological characteristics and measurement of Sweet potato weevil

The newly hatched larvae of *C. formicarius* (Plate 05) were transferred in petridishes. The morphological characteristics of the larvae (Plate 06) and pupae (Plate 08) were studied and recorded during the period of larval and pupal development, respectively. Different growth and development stages of *C. formicarius* such as larval period, pupal period and adult (Plate 09, 10) longevity were recorded during the study. The incubation period was measured by time interval between egg laying and larval hatching.

3.1.5 Design of the experiment

Three experiments were laid out in CRD (Completely randomized design) with five (5) replications.

3.1.6 Data recorded: Data were recorded in the following parameters to study the biology:

- Incubation period
- Larval period
- Larval mortality

• Pupal period
• Pupal mortality
• Adult emergence
• Adult longevity

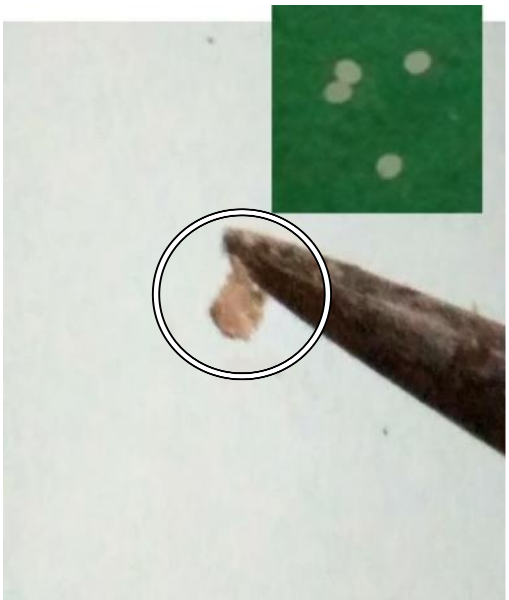

Plate 04: Egg of sweet potato weevil under Microscope

Plate 5: A newly emerge larvae of sweet potato weevil under Microscope

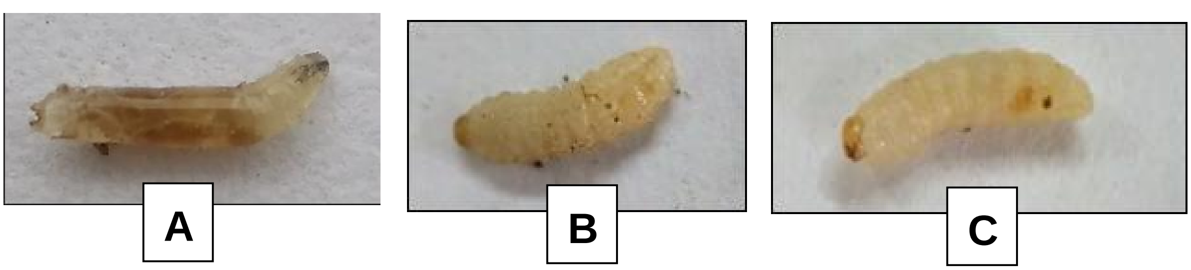

Plate 6: A newly emerge 1st instar larvae (A), 2nd instar larvae (B) and 3rd instar larvae of sweet potato weevil under Microscope

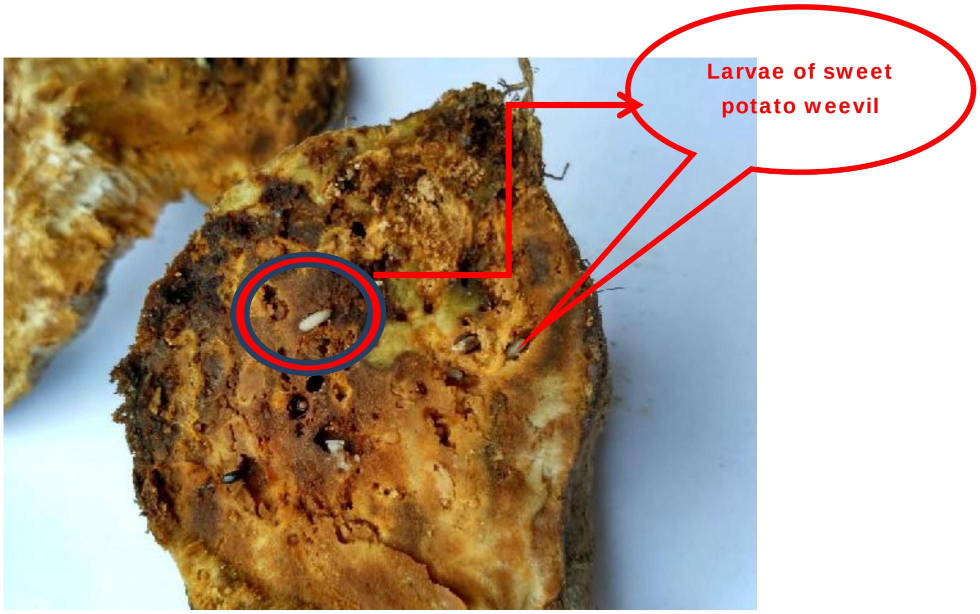

Plate 07: Infested sweet potato with larvae of *C. formicarius* during the study period in laboratory

.

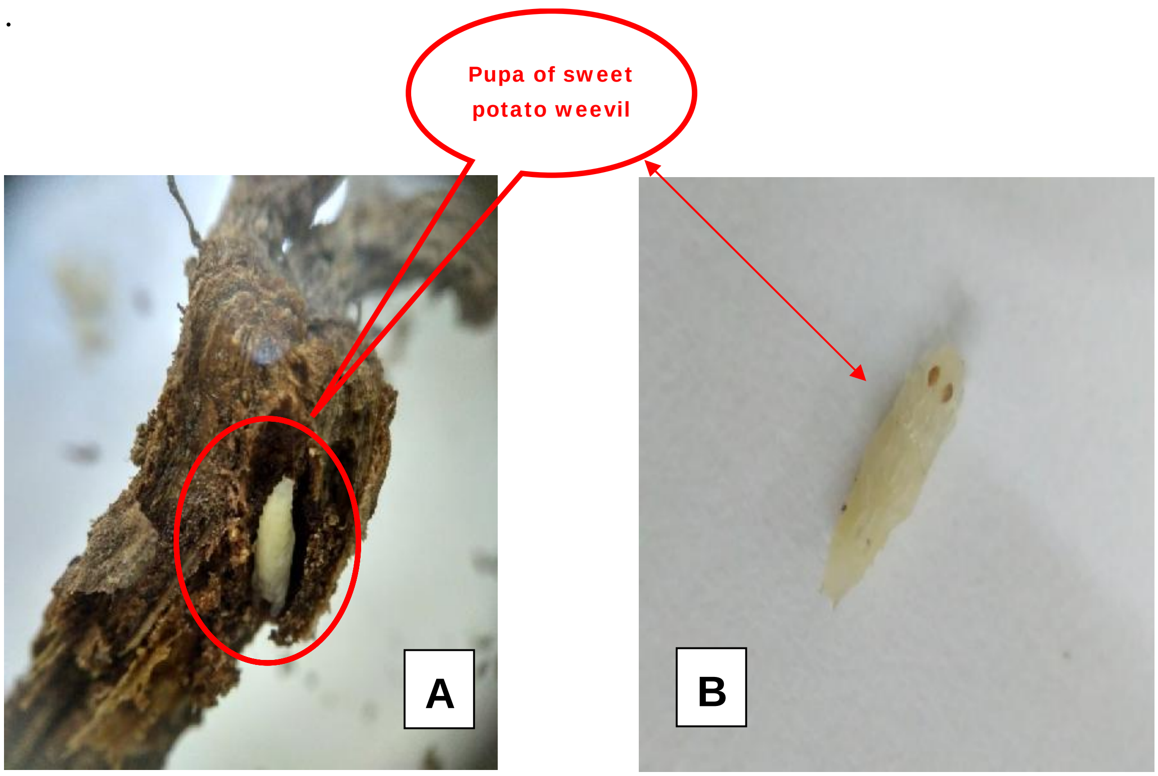

Plate 08: Pupa of sweet potato weevil in chamber on sweet potato (A) and microscopic view of pupa (B) during the study period

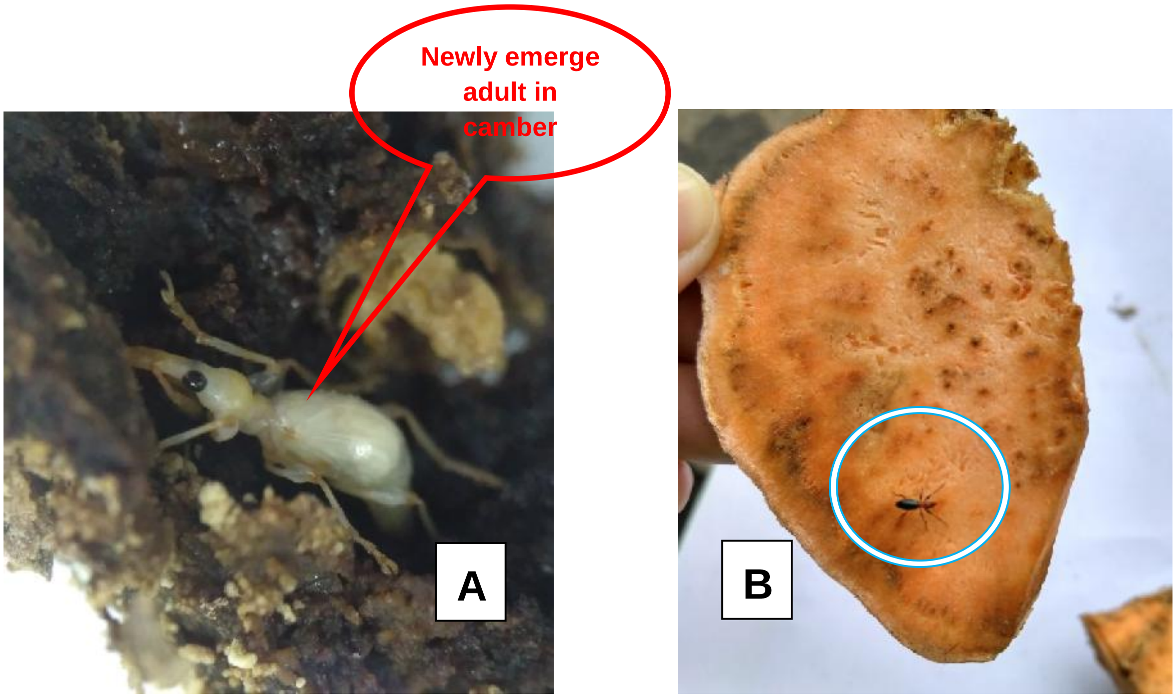

Plate 09: Newly emerge adult (A) under microscope and mature adult (B) of sweet potato weevil

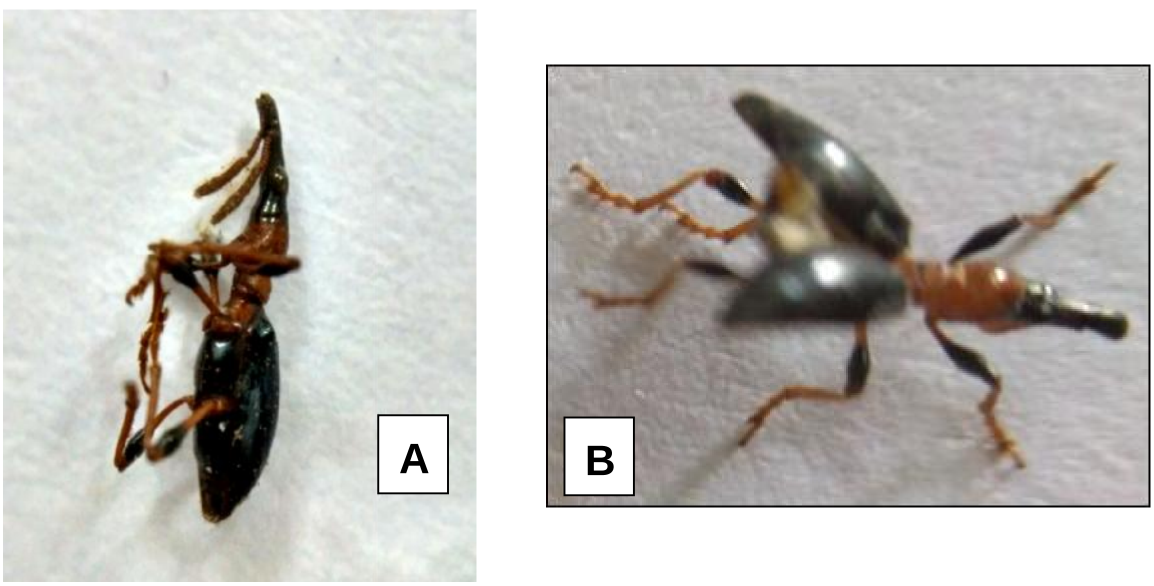

Plate 10: Wing less adult (A) and winged adult (B) of sweet potato weevil under microscope

Experiment 2: The extent of damage of sweet potato due to infestation by Sweet potato weevil, *C. formicarius* in storage condition

The experiment was conducted to study the extent of damages in different sweet potato infested by sweet potato weevil during the period from April 2016 to march 2017. A brief description of the experimental site, experimental design, data collection and analysis of different parameters under the following headings has been explained below:

3.2.1 Preparation of Test Materials

Sweet potato was collected from local market of Dhaka city at August 2017 to carry out the study. The sweet potatoes were cleaned, dried and sort out from the damage unhealthy fruits and stored rearing case with airtight condition to keep free from the insects and microorganisms.

3.2.2 Collection of sweet potato weevil

The process of collection was described of the previous Experiment no. 3.2

3.2.3 Experimental design and layout

The experiment was laid out in the ambient condition of laboratory considering in

CDR with 5 (five) replications.

3.2.4 Experimental material

1kg of different variety of sweet potato as BARI 2, BARI 12 and local variety were kept as experimental material in each rearing case with 10 pairs of sweet potato weevil for assessment the damage percentage (Plate 11)

Plate 11: Experimental set up with different sweet potato to determine the damage assessment by *C. formicarius*

3.2.4.1 Sweet potato variety: BARI sweet potato 2(kamala sunduri)

Vine of BARI sweet potato 2 (kamala sunduri) [plate 12] normally color green but apical portion violate, leaves green color but immature leaf violet, vain of alter leaf colorless, tuber skin orange, flesh soft, orange, parabola shape , tuber weight 180-220g, crop duration 135-140days. This variety is cultivated throughout the Bangladesh.

Plate 12: BARI sweet potato 2 (kamala sundari) used as a Experimental material to determine the damage assessment by *Cylas formicarius*

3.2.4.2 Sweet potato variety: BARI sweet potato 4

BARI sweet potato 4 (plate 13) is high yielding varity, tuber and flesh off white color, tuber weight 175-195 g, tuber parabola shape, crop duration 120- 130 days, carotene rich and medium dry flesh, leaf green but immatur leaf violet. Weevil attack lower.

Plate 13: BARI sweet potato 4 used as an experimental material to determine the damage assessment by *Cylas formicarius*

3.2.4.3 Local variety of sweet potato

Local variety of sweet potato (plate 14) is moderate yielding varity, tuber and flesh white reddish color, crop duration 130- 140days, carotene rich, rich in vitamine and medium dry flesh, leaf green. Weevil attack modarate.

Plate 14: Local variety sweet potato used as an experimental material to determine the damage assessment by *C. formicarius*

3.2.5 Adult Mortality and New Emergence

1Kg of insect free different variety of sweet potatoes was taken into each rearing case separately. Then 10 pairs of newly emerged adult beetle were released carefully in to each container. Insect mortality was recorded at 4 days intervals up to 90 days. The rearing case were observed from outside to examine death of released weevil. The mortality of the adult was recorded against BARI sweet potato 2, BARI sweet potato 4 and Local variety of sweet potato. The adult mortality was recorded and converted into percent.

$$\text{Per cent of mortality} = \frac{\text{No. of dead insects}}{\text{Total no. of insects}} \times 100$$

After 23 – 33 days, new adults started emerging from those sweet potato tubers. The counting of emergent adult weevil was made by opening the net. After beginning, few weevils came out from the rearing case at first and the rest of them came out after gently shakings the rearing case.

3.2.6 Extent of damage and weight loss of different sweet potato

The final weight of tubers was taken to obtain weight loss. Sieving and winnowing was done to clean the tubers. The clean tubers except those having scars in each container were weighted separately. The weight losses of sweet potato tubers were found out by subtracting the final weight from the initial weight (1kg). The weight losses were converted into percentage of weight loss of tubers respectively. The percentage of weight loss was calculated as follows:

$$\text{\% Infestation (by weight)} = \frac{\text{Weight of infested tubers}}{\text{Total weight of tubers}} \times 100$$

$$\% \text{ Weight loss due to infestation} = \frac{\text{Initial weight} - \text{Final weight of tubers}}{\text{Initial weight of tubers}} \times 100$$

3.2.7 Statistical Analysis

The observed data were statistically analyzed by Completely Randomized Design (CRD). Mean values were adjusted by Duncan's Multiple Range Test (DMRT)(Duncan, 1951). All statistical analysis were done through a package program namely Microsoft Statistical (MSTAT) Program in a computer.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Biology of sweet potato weevil, *Cylas formicarius* on sweet potato in laboratory

Duration of development of immature stages

Eggs were found laid singly in cavities in the roots and stems of sweet potato and each cavity or hole was then covered with a white or grayish material. The eggs were pale yellow in colour, oval in shape and hardly seen without scratching the hard material that covers them. The incubation period was found to be on average 4.6±6.18 days under room conditions (Table 1). This finding is similar to other research. Such as, The shortest incubation period recorded, 4 days, occurred during July and August, when the average mean temperature was above 80°F (Cockerham *et al*, 1954).

Table 1: Development in days of pre-imaginal stages of sweet potato weevil, *C. formicarius* under room condition (July/August, 2017)

Rearing cage no.	Number of eggs hatched after(days)/per tuber					Average days (Mean ±SD)
	3 DAH	4 DAH	5 DAH	6 DAH	7 DAH	
1	0	13	0	4	6	4.6±5.36
2	1	1	17	0	3	4.4±7.12
3	1	10	0	3	5	3.8 ±3.96
4	0	9	0	6	2	3.4±3.97
5	0	15	3	5	0	4.6±6.18

4.1.1 Developmental period of different life stages of sweet potato weevil, *C. formicarius*

The newly hatched larva is yellowish white with a light brown head. Total duration of 13.60±1.81 and 6.20±1.09 days were required for larval stage and pupal stage respectively. Most of Adults were wingless but some were winged (Plate 14) and adult longevity of sweet potato weevil (*C. formicarius*) was 62.6±9.208 days (table 2). Chamber formed by larvae of sweet potato weevil (*C. formicarius*) before pupation. There was a special characteristic of pupa of sweet potato weevil that 3rd instar larvae create chambers for pupation (plate16). In chambers they spend their pupal life that is inactive stage of their life cycle. Its duration was from 5-8days. This finding is similar to other research. Such as according to Capinera (1998) recorded that Temperature is the principal factor affecting larval development rate, with larval development (not including the prepupal period) occurring in about 10 and 35 days at 30^o and 24^o C, respectively. Duration of the pupal stage averages 7 to 10 days, but in cool weather it may be extended to up to 28 days. But the findings about adult longevity is dissimilar to other research such as Ames and Braun (1996) reported that adult longevity is 2 ½ to 3 ½ months.

Table 2: Development period of different life stages of sweet potato weevil on sweet potato in laboratory condition

Development stage	Duration (days) (Mean ±SD)	Data range
Larval period	13.60±1.81	12-16
Pupal period	6.20±1.095	5-8
Adult longevity	62.6±9.208	52-75

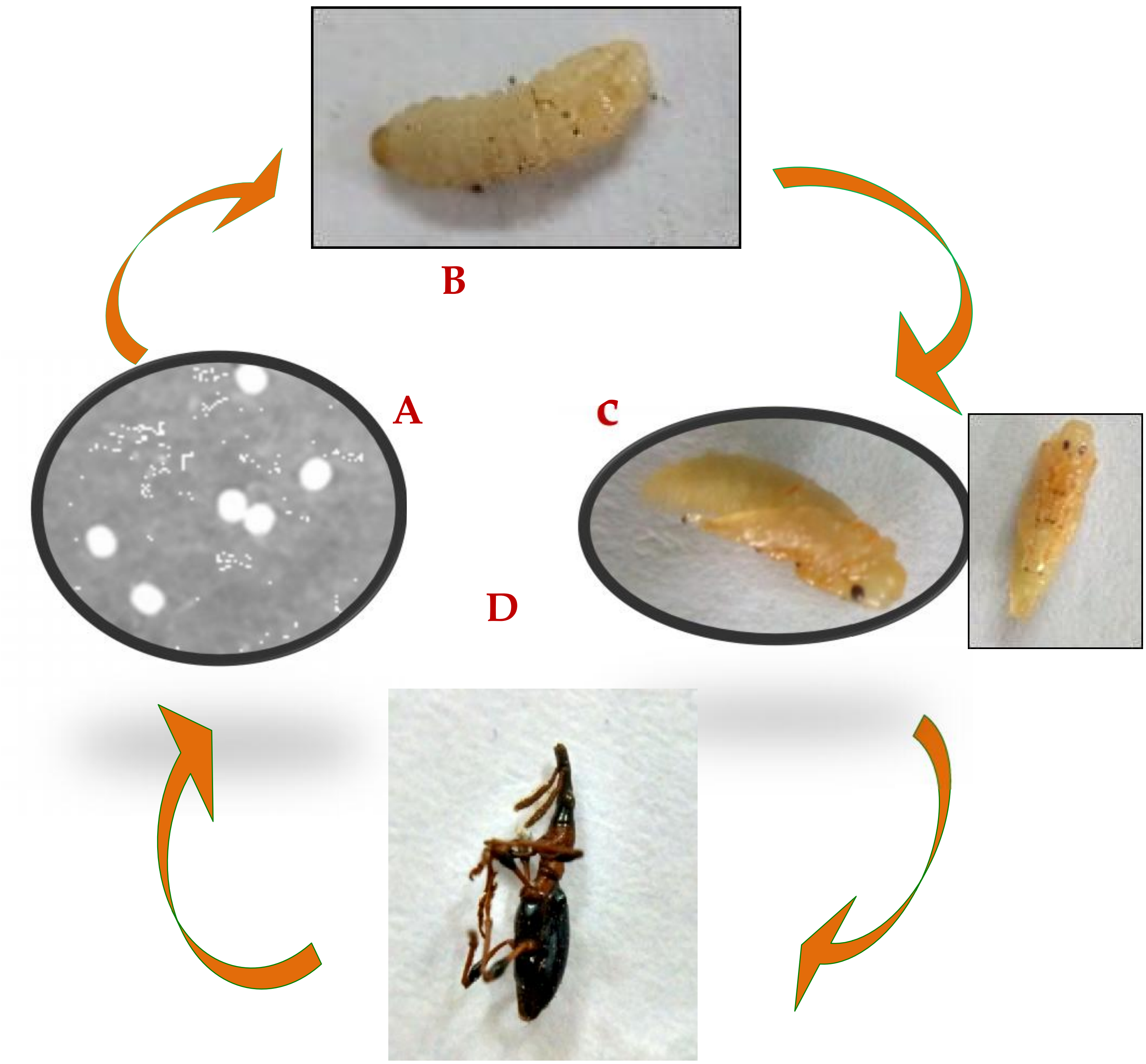

Plate 15: Life cycle of sweet potato weevil, *C. formicarius* (L), **A.** Egg, **B.** Larva, **C.** Pupa and **D.** Adult

4.1.2 Morphometric measurement of different life stages of sweet potato weevil, *C. formicarius*

The length of egg was 0.68 ±0.083 mm and width was 0.32±0.083 mm; 1st, 2nd and 3rd instar larval (plate 6) length were 1.6 ±0.387 mm, 3.76 ±0.364 mm and 5.88 ±0.258 mm respectively and larval width were 0.28±0.030 mm, 0.526±0.074 mm and 0.81 ±0.045 mm respectively; Pupal length 6.2 ±0.367mm and width 1.006 ±0.138mm; the length of adult was 6.82 ±0.49mm and width 1.8 ±0.158 mm in table 3.

Table 3: Morphometric measurement of different life stages of sweet potato weevil in the laboratory

Life stage	Size(mm)			
	Length(mm) (Mean ±SD)	**Data range**	**Width(mm) (Mean ±SD)**	**Data range**
Egg	0.68 ±0.083	0.6-0.8	0.32±0.083	0.2-0.4
Larval instar				
1st	1.6 ±0.387	1.2-2.1	0.28±0.030	0.25-0.32
2nd	3.76 ±0.364	3.3-4.2	0.526±0.074	0.42-0.6
3rd	5.88 ±0.258	5.5-6.2	0.81 ±0.045	0.76-0.82
Pupa	6.2 ±0.367	5.8-6.7	1.006±0.138	0.88-1.2
Adult	6.82 ±0.491935	6.2-7.4	1.8 ±0.158114	1.6-2

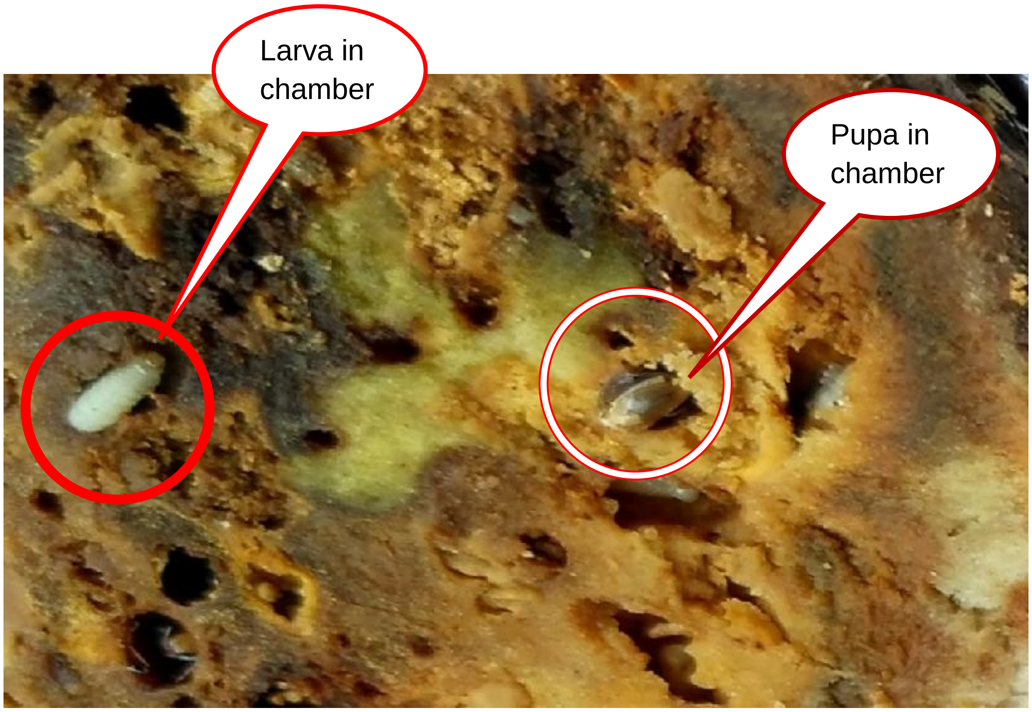

Plate no. 16: Larva and pupa of sweet potato weevil in Chamber of infested sweet potato

Plate no. 17: Infested sweet potato with larvae and pupae of sweet potato weevil (*C. formicarius*) after the 1stgeneration

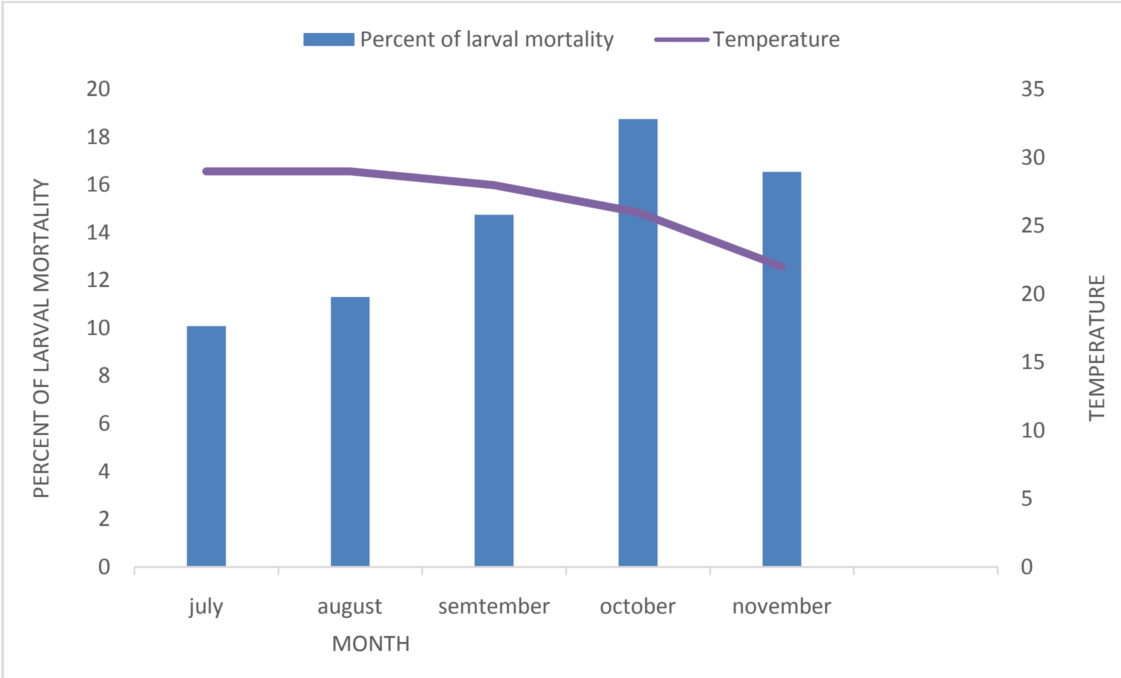

Figure no. 1: Larval mortality of sweet potato weevil (*Cylas formicarius*) at different month during the study period on the basis of temperature

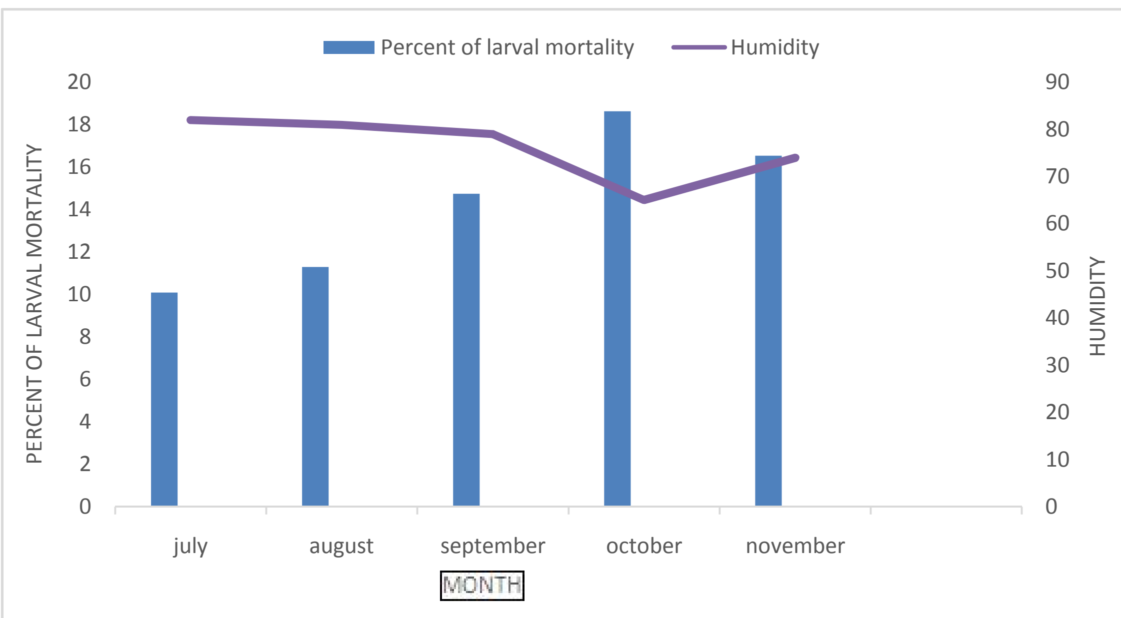

Figure no. 2: Larval mortality of sweet potato weevil (*C. formicarius*) at different months during the study period on the basis of humidity

4.1.3 Larval mortality of sweet potato weevil, *C. formicarius*

The newly hatched larvae were more or less same in July and august. Whereas the highest percentage of larval mortality was observed in October, and the lowest percentage of larval mortality was observed in July (Figure 1 and 2), with total number of larval mortality 19.2 (Appendix I).

4.1.4 Pupal mortality of sweet potato weevil, *C. formicarius*

The highest percentage of pupal mortality was observed in October , whereas the second highest was in November and the lowest percentage of pupal mortality was observed in month of july (Figure 4), with total number of pupal mortality 21.4 (Appendix II).

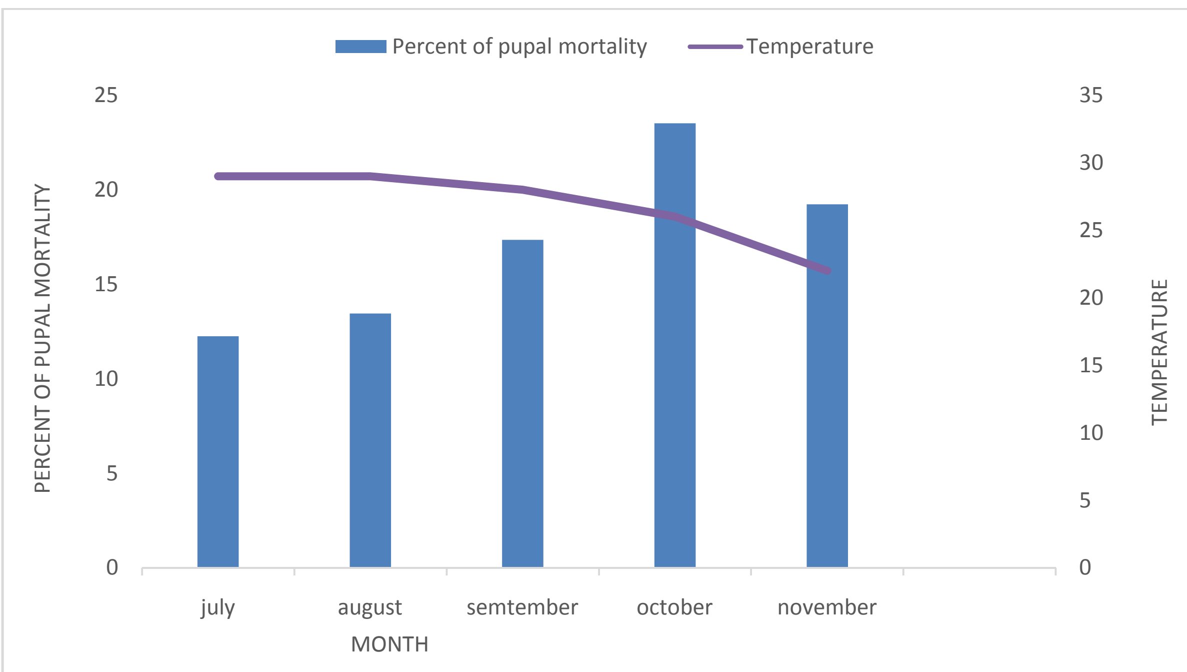

Figure no. 3: Pupal mortality of sweet potato weevil (*Cylas formicarius*) at different months during the study period on the basis of temperature

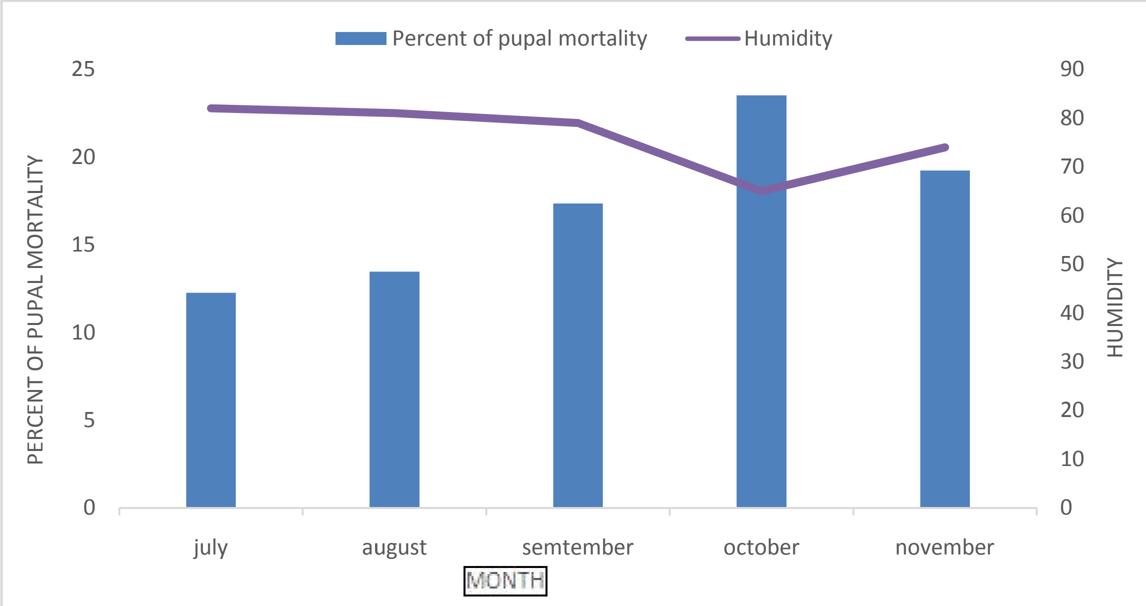

Figure no. 4: Pupal mortality of sweet potato weevil (*Cylas formicarius*) at different months during the study period on the basis of humidity

4.1.5 Newly adult emergence

Table 4: Number of larvae, number of pupa and adult emerged of sweet potato weevil in laboratory condition

Rearing cage number	Number of hatched larvae/5 selected fruit	Number of pupae/5 selected fruit	Number of emerged adults/5 selected fruit
Set I	115	102	78
Set II	122	104	90
Set III	109	98	81
Set IV	102	83	67
Set V	127	106	93
(Mean ±SD)	115±9.974	98.6±9.208	81.8 ±10.32957

From table 4, it was observed that, the newly hatched adults were more or less same in set-I and set- III. Whereas the highest adult emergence was observed from set- V, and the lowest number adult emergence of was observed from set-IV.

4.2. Damage assessment of sweet potato weevil in different sweet potato

4.2.1 Status of different sweet potato in 1st and 2nd generation by weight basis

At the 1st generation of sweet potato weevil (*C. formicarius*): Status of different sweet potato in terms of healthy, infested and % infestation showed statistically by significant variation (Table 5) under the present trial for the damage assessment of different stored sweet potatoes by sweet potato weevil. In 1st generation on weight basis, the highest weight of healthy tubers (764.0g) was recorded in BARI sweet potato 2. The lowest was observed in BARI sweet potato 4(506.60g) which was statistically identical with local variety of sweet potato (585.0g). The highest weight of infested sweet potato was observed in BARI sweet potato 2 (489.60g) which was statistically identical by local variety of sweet potato (412.20g). The lowest weight of infested sweet potato was recorded in BARI sweet potato 4 (233.0g). Considering of % infestation, the highest percent of infestation was recorded from BARI sweet potato 2 (49.15%) which was statistically similar to local variety of sweet potato (41.34 %), while low percent of infestation was recorded in white sweet potato (23.37%). (Table 5).

Table 5. Effect of different sweet potatoes on percent infestation caused by sweet potato weevil (*C. formicarius*) in stored condition at the 1st generation

Variety	Weight of healthy tuber	Weight of infested tuber	% of infestation
BARI sweet potato 2 (Kamala Sunduri)	506.60 c	489.60 a	49.15 a
BARI sweet potato 4	764.00 a	233.00 c	23.37 c
Local variety of sweet potato	585.00 b	412.20 b	41.34 b
LSD $_{(0.01)}$	61.86	40.42	3.08
CV (%)	5.18	5.53	4.20

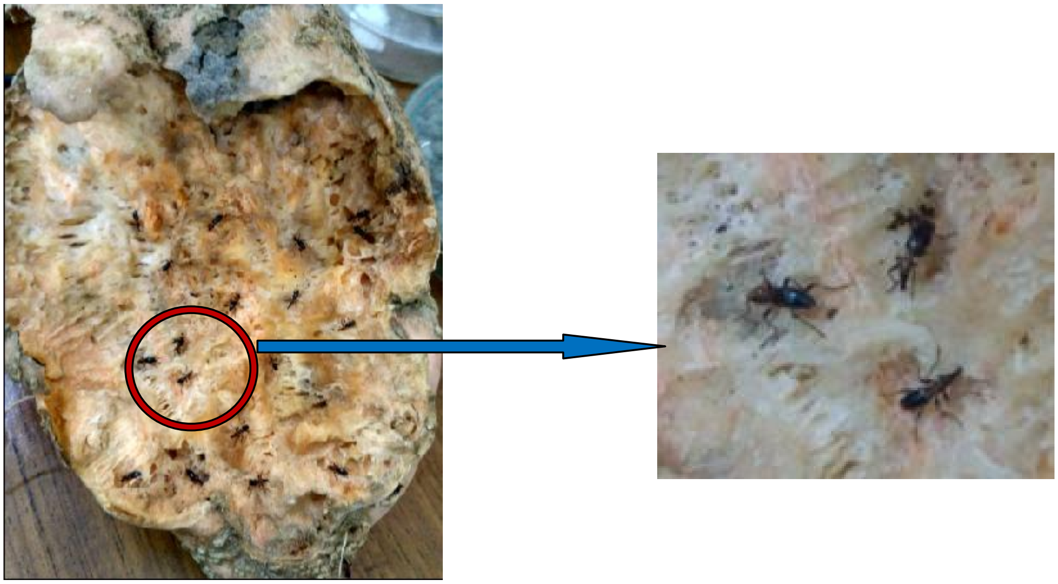

Plate 18: Infested BARI sweet potato-02 (KAMALA SUNDURI) by sweet potato weevil

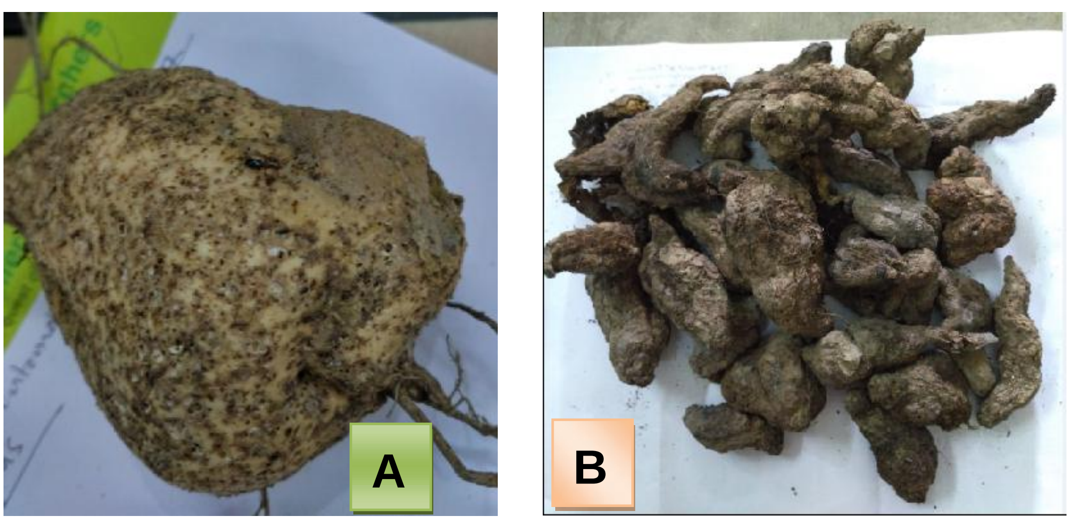

Plate 19: Infested **BARI sweet potato-04** by sweet potato weevil after 1st generation (A) and 2nd generation (B)

At the 2nd generation of sweet potato weevil (*C. formicarius*): In 2nd generation on weight basis, the highest weight of healthy tuber was BARI sweet potato 4 (480.40g) and local variety of sweet potato (248.20g). The lowest was observed in BARI sweet potato 2 (0.00g). In case of infested fruits, the highest weight of infested tuber was observed in BARI sweet potato 2 (988.60g). Whereas the weight of infestation in local variety of sweet potato (746.40g). The lowest weight of infested tuber was recorded in BARI sweet potato 4 (513.80g) which Considering of % infestation, the highest infestation was recorded from BARI sweet potato 2 (100.00%) which was statistically different from other sweet potato and followed by local variety of sweet potato (75.05%) while low percent of infestation was recorded in BARI sweet potato 4 (51.68%) in Table 6.

Table 6. Percent of Infestation of sweet potato weevil (*C. formicarius*) in stored sweet potato at the 2nd generation by weight basis

Variety	Weight of healthy tuber	Weight of infested tuber	% of infestation
BARI sweet potato 2 (Kamala Sunduri)	0.00 c	988.60 a	100.00 a
BARI sweet potato 4	480.40 a	513.80 c	51.68 c
Local variety of sweet potato	248.20 b	746.40 b	75.05 b
LSD $_{(0.01)}$	35.05	39.17	3.96
CV (%)	7.47	2.70	2.71

4.2.2 Weight loss of different sweet potato

At the 1st generation of sweet potato weevil (*C. formicarius*): Status of different sweet potato in terms of initial, final and % of weight loss showed statistically by significant variation (Table 7) under the present trial for the damage assessment of different

Plate 20: Healthy sweet potato of Local variety (A) Infested **sweet potato of** local variety by sweet potato weevil after 2^{nd} generation (B)

variation (Table 7) under the present trial for the damage assessment of different stored sweet potatoes by sweet potato weevil. In 1st generation on weight basis, the initial weight of healthy tubers (1000g) was recorded in BARI sweet potato 2, BARI sweet potato 4 and local variety of sweet potato. The highest weight of infested sweet potato was observed in BARI sweet potato 2 (996.20g) whereas the lowest weight of infested tuber was recorded in BARI sweet potato 4 (997.20 g) which was statistically identical by local variety of sweet potato (997.20 g). Considering of % of weight loss, the final highest weight loss was recorded from BARI sweet potato 2 (0.38%). And the final lowest weight loss was recorded in BARI sweet potato 4 (0.26%) which was statistically similar to local variety of sweet potato (0.28%) in Table 7.

Table 7. Effect of different sweet potatoes on percent of weight loss and total weight caused due to sweet potato weevil (*C. formicarius*) in stored condition at 1st generation

Variety	Initial weight of tuber	Final weight of tuber	% of weight loss
BARI sweet potato 2 (Kamala Sunduri)	1000	996.20	0.38 a
BARI sweet potato 4	1000	997.00	0.26 c
Local variety of sweet potato	1000	997.20	0.28 b
LSD $_{(0.01)}$	NS	NS	0.02
CV (%)	0.00	0.13	4.01

At the 2nd generation of sweet potato weevil (*C. formicarius*): In 2nd generation on weight basis, the initial weight of healthy tuber was BARI sweet potato 4 (997.00g) and local variety of sweet potato (997.20 g). The lowest was observed in BARI sweet potato 2 (996.20 g). In case of infested tubers, the highest final weight of infested tuber was observed in BARI sweet potato 2 (988.60 g), whereas, the final weight of infestation in local variety of sweet potato (994.60 g). The lowest weight of infested tuber was recorded in BARI sweet potato 4 (994.20g) which Considering of % infestation, the highest weight loss was recorded from BARI sweet potato 2 (0.76%) which was statistically different from other sweet potato and followed by local variety of sweet potato (0.30 %) while low percent of infestation was recorded in BARI sweet potato 4 (0.28%) in Table 8.

Table 8. Effect of different sweet potatoes on percent infestation and total weight caused by sweet potato weevil (*C. formicarius*) in stored condition at 2nd generation

Variety	Initial weight of tuber	Final weight of tuber	% of weight loss
BARI sweet potato 2 (Kamala Sunduri)	996.20	988.60 b	0.76 a
BARI sweet potato-4	997.00	994.20 a	0.28 b
Local variety of sweet potato	997.20	994.60 a	0.30 b
LSD $_{(0.01)}$	NS	3.31	0.02
CV (%)	0.13	0.17	3.37

4.2.3 Correlation between percent of infestation and weight loss of BARI sweet potato 2 by *Cylas formicarius*

Correlation study was done to establish the relationship between percent of infestation and weight loss of BARI sweet potato 2. From the figure 05, it was revealed that positive correlation was observed between the parameters. It was evident that the equation y= 0.007x + 0.012 gave a good fit to the data and the co-efficient of determination (R^2=1) fitted regression line had a significant regression co-efficient. It may be concluded from the figure that percent of infestation was strongly as well as positively correlated with weight loss of sweet potato. Weight loss of BARI sweet potato 2 was increased due to increase of percent of infestation.

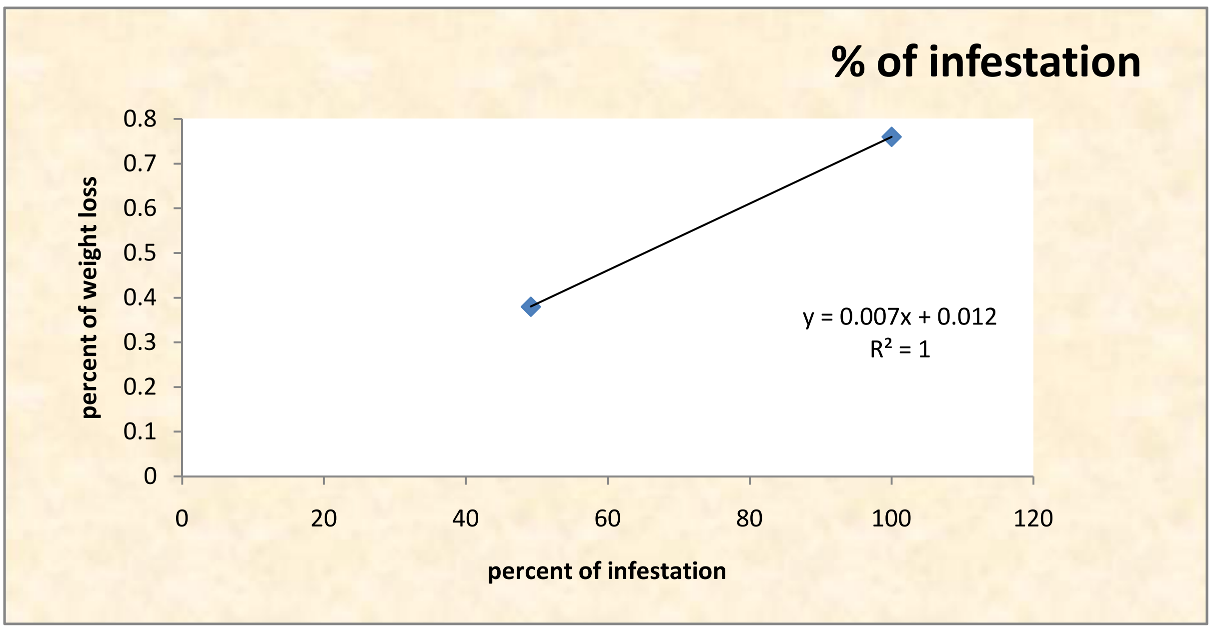

Figure 05: Relationship between percent of infestation and weight loss of BARI sweet potato 2 by *Cylas formicarius* at the 1st and 2nd generation

4.2.4 Correlation between percent of infestation and weight loss of BARI sweet potato 4 by *Cylas formicarius*

Correlation study was done to establish the relationship between percent of infestation and weight loss of BARI sweet potato 4. From the figure 06, it was revealed that positive correlation was observed between the parameters. It was evident that the equation y= 0.000x + 0.243 gave a good fit to the data and the co-efficient of determination (R^2=1) fitted regression line had a significant regression co-efficient. It may be concluded from the figure that percent of infestation was strongly as well as positively correlated with weight loss of sweet potato. Weight loss of BARI sweet potato 4 was increased due to increase of percent of infestation.

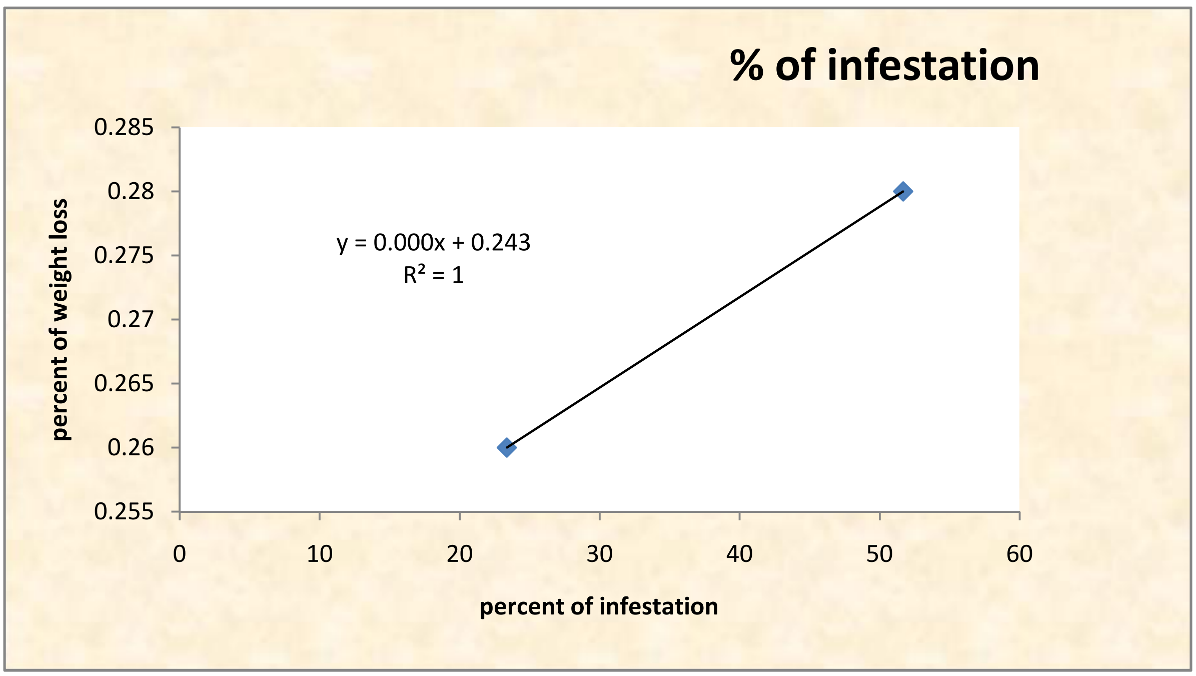

Figure 06: Relationship between percent of infestation and weight loss of BARI sweet potato 4, by *Cylas formicarius* at the 1st and 2nd generation

4.2.5 Correlation between percent of infestation and weight loss of local variety of sweet potato by *Cylas formicarius*

Correlation study was done to establish the relationship between percent of infestation and weight loss of local variety of sweet potato. From the figure 07, it was revealed that positive correlation was observed between the parameters. It was evident that the equation y=0.000x + 0.255 gave a good fit to the data and the co-efficient of determination (R^2=1) fitted regression line had a significant regression co-efficient. It may be concluded from the figure that percent of infestation was strongly as well as positively correlated with weight loss of sweet potato. Weight loss of local variety was increased due to increase of percent of infestation.

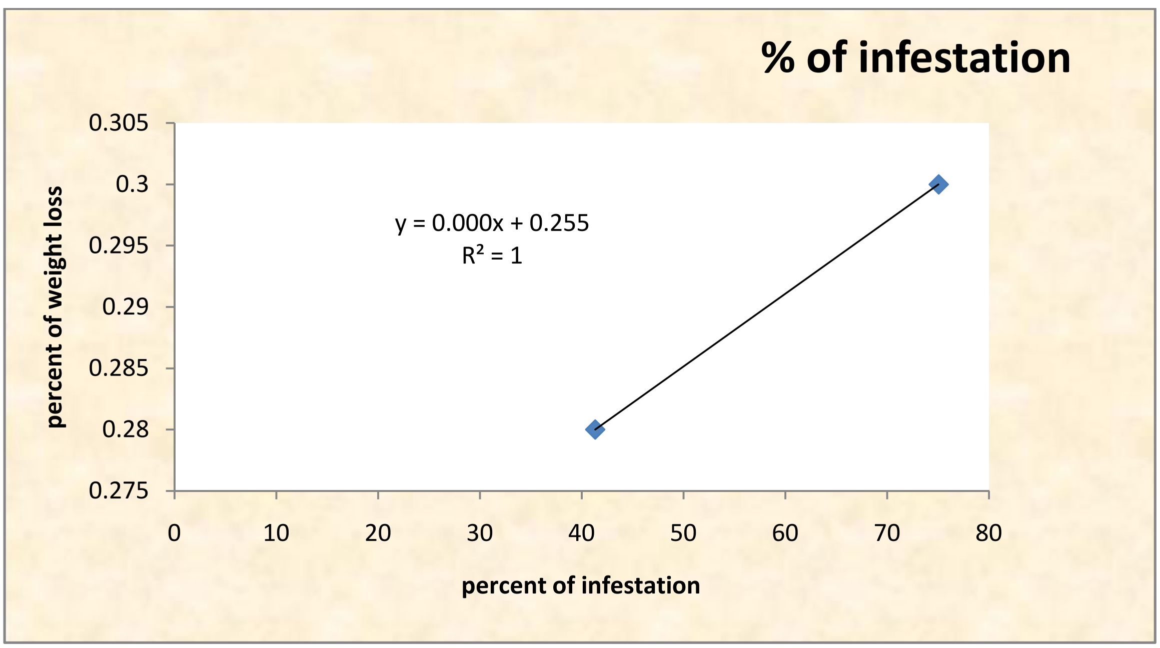

Figure 07: Relationship between percent of infestation and weight loss of local variety of sweet potato by *Cylas formicarius* at the 1st and 2nd generation

CHAPTER V

SUMMARY AND CONCLUSION

Two experiments were conducted in the laboratory of the Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from July to December, 2017 to damage assessment and study on the biology of sweet potato weevil *Cylas formicarius* in different sweet potato such as BARI sweet potato 02 (kamala sunduri), BARI sweet potato 4 and local variety of sweet potato were used as experimental materials.

Experiment-1: Study on the biology of sweet potato weevil *C. formicarius* in the laboratory

An average incubation period was 4.6±6.188 days under room conditions on BARI sweet potato-2 in laboratory condition. Total 13.60±1.81 and 6.20±1.095 days were required for larval stage and pupal stage respectively. Adult longevity of sweet potato weevil *C. formicarius* was 62.6±9.208 days.

The length of egg was 0.68 ±0.083 mm and width 0.32±0.083 mm; 1st, 2nd and 3rd instar larval length were 1.6 ±0.38 mm, 3.76 ±0.36 mm and 5.88 ±0.25 mm respectively and larval width were 0.28±0.03 mm, 0.52±0.07 mm and 0.81 ±0.04 mm respectively; Pupal length 6.2 ±0.36 mm and width 1.0 ±0.13 mm; the length of adult was 6.82 ±0.49 mm and width 1.8 ±0.15 mm. The newly hatched larvae were more or less same in July and august. Whereas the highest percentage of larval mortality was observed in October, and the lowest percentage of larval mortality was observed in July. There is a special characteristic of pupa of sweet potato weevil that their instar larvae create chambers. In chambers they spend their pupal life that is inactive stage of their life cycle. Its duration was from 5-8 days. The highest percentage of pupal mortality was observed in October, whereas the second highest was in November and the lowest percentage of pupal mortality was observed in month of July The highest adult emergence was observed from set- V, and the lowest number adult emergence of was observed from set-IV.

Experiment 2: The damage assessment of sweet potato due to infestation by sweet potato weevil *C. formicarius*

At the 1st generation on weight basis, the highest weight of healthy tubers (764.0g) was recorded in BARI sweet potato 4. The lowest was observed in BARI sweet potato 2 (506.60g) which was statistically identical with local variety of sweet potato (585.0g). The highest weight of infested sweet potato was observed in BARI sweet potato 2 (489.60g) which was statistically identical by local variety of sweet potato (412.20g). The lowest weight of infested tuber was recorded in BARI sweet potato 4 (233.0g). Considering of % infestation, the highest infestation was recorded from BARI sweet potato 2 (49.15%) which was statistically similar to local variety of sweet potato (41.34 %), while low percent of infestation was recorded in BARI sweet potato 4 (23.37%).

At 2nd generation on weight basis, the highest weight of healthy tuber was BARI sweet potato 4 (480.40g) and local variety of sweet potato (248.20g). The lowest was observed in BARI sweet potato 2 (0.00g). In case of infested tubers, the highest weight of infested tuber was observed in BARI sweet potato 2 (988.60g). Whereas the weight of infestation in local variety of sweet potato (746.40g). The lowest weight of infested tuber was recorded in BARI sweet potato 4 (513.80g) which Considering of % infestation, the highest percent of infestation was recorded from BARI sweet potato 2 (100.00%) which was statistically different from other sweet potatoes and followed by local variety of sweet potato (75.05%) while low percent of infestation was recorded in BARI sweet potato 4 (51.68%).

CONCLUSION

The sweet potato weevil *Cylas formicarius* is one of the most serious pests of sweet potato. They attack sweet potato both in field condition and stored condition. The weevil develops through egg, three larval instars, pupa, pre-pupa and adult stages. The duration of weevil development stage duration 13.60±1.81 and 6.20±1.095 were required for larval stage and pupal stage respectively. Adult longevity of sweet potato weevil *C. formicarius* was 62.6±9.208days. Considering the adult mortality or dead of insects, adult emerged of sweet potato weevil, weight of healthy and infested spices and percent infestation, the present study showed that the highest damage occurs in BARI sweet potato 2 and lowest damage occurs in BARI sweet potato 4 respectively by sweet potato weevil. Information on the biology and host use pattern of *C. formicarius* may help to explain how various stored sweet potato are affected by this sweet potato weevil; and may lead to develop appropriate pest management strategies for this insect pest.

Recommendation

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

- ➢ Influence or impact of different environmental factors may be studied studying the biology of the pest in different seasons of the year

CHAPTER VI

REFERENCES

Ahmed, M.T., Nath, S.C., Sorwar, M.A., Rashid, M.H. (2015). Cost-effectiveness and resource use efficiency of sweet potato in Bangladesh. *J. of Agril. Eco. and Rural Dev*. **2**: 26-31.

Alcazar, J., Cisneros, F. and Morales, A. (1997). "Large-scale implementation of IPM for sweet potato weevil in Cuba: a collaborative effort," *Working Paper (CIP). Agri*. **14**(5): 257-282.

Ames, T., Smit, N.E.J.M., Braun, A.R., O'Sullivan, J.N. and Skoglund, L.G. (1996). Sweet potato: Major Pests, Diseases, and Nutritional Disorders. *Int. potato center* (CIP). Lima, peru.

Anonymous, (1984). Insect Pests of Sweet potato, Shanghai Science Press, Shanghai, China.

Asian Vegetable Research and Development Center (AVRDC) (1990). AVRDC Progress Report Summaries 1990, *Asian Vegetable Research and Development Center*, Shanhua, Taiwan.

Bahagiawati, A.H. (1989). Bionomics and Control of the Sweetpotato Weevil, *Cylas Formicarius* in Indonesia, Bogor Research Institute for food crops, Bogor, Indonesia.

Bhat, P.S. (1996). Tropical Tuber Crops: Problems, Prospects and Future Strategies, Science Publishers, Chennai, India.

Braun, A.R., and van de Fliert, E. (1999). "Evaluation of the impact of sweet potato weevil (*Cylas formicarius*) and of the effectiveness of *Cylas* sex pheromone traps at the farm level in Indonesia," *International J. of Pest Management*. **45**(2): 101–110.

Burns, R. (1999). Sweet potato weevil putan industry at risk in north east Texas. *Texas Agril. Extension Service*, Texas, USA.

Capinera, J.L. (2001). Capinera Handbook of Vegetable Pests, Academic Press, San Diego, Calif, USA.12p

Capinera, J.L. (1998). Sweet potato Weevil, *Cylas formicarius* (Fabricius) (Insecta: Coleoptera: Brentidae (=Curculionidae)), University of Florida, IFAS.

Chalfant, R.B., Jansson, R.K., Seal, D.R. and Schalk, J.M. (1990). Ecology and management of sweet potato insects. *Annual review of entomol*. **35:** 157-180.

Co.MSTocK, J.H. (1879). The sweet potato root borer. Ent. Rpt. *In Rpt. of Comm. of Agri, illus*. pp. 249-250

Cockerham, K.L., Deen, O.T., Christian, M.B., Newsom, L.D. (1954). The biology of the sweet potato weevil. *Louisiana Agricultural Experiment Station Techincal Bull.* 483.30 pp.

CoNRADi,A.F. (1907). The sweet potato root borer. *Tex. Agri. Expt. Sta.Bui*. **93**: 16

Devi, M., Indira, K. and Niranjana, R.F. (2014). “Biology of sweet potato weevil, *Cylas formicarius* F. on sweet potato”, Department of Agricultural Entomology, *Tamil Nadu Agricultural University*. **38**(1): 53-57.

Dinh, N.V., Khang, H.L., Thew N.V. (1995). Preliminary Results of IPM Application to Sweet potato in ThanhBinh, Agricultural Publishing House, Hanoi, Vietnam.

Fabricius, J.G. (1792-94).Original description as *Breiitus formicarius*. *Ent. Syst*. **2**(13):549.

FAOSTAT (2011). Food and Agricultural Organization.

FAOSTAT/ FAO(2015). Food and Agriculture Organization of the United Nations, Food and Agriculture Organization Statistical Databases.

Fuglie, K.O. (2007). “Priorities for sweet potato research in developing countries: results of a survey,” *Hort. Sci*. **42**(5): 1200–1206.

Fukuda, K. (1933). Insect Pests of Sweet potato in Formosa. Part 1. *The Sweet potato weevils," Agricultural and Biological Chemistry.* **37**: 18–22

Gapasin, R.M., (1989). "Studies on the major diseases and insect pests of sweet potato at VISCA, the Philippines," in Weetpotato Research and Development for Small Farmers, Mackay, K.T., Palomar, M.K.andSanico, R.T. Eds., SEAMEO SEARCA College, Laguna, Philippines. p. 151–168.

Gomi, T., Nagasaka, M., Fukuda, T. and Higahara, H. (2007). "Shifting of the life cycle and life-history traits of the fall webworm in relation to climate change," *Entomologia Experimentaliset Applicata*. **125**(2): 179–184.

Gonzales, S. S. (1925). The Sweet potato Weevil (*Cylas formicarius* Fabr.) Philippine.

Hahn S.K. and Leuschner, K. (1982). "Breeding of sweet potato for weevil resistance," in Proceedings of the 1st International Symposium on Sweet potato, Villareal, R.L. and Griggs, T.D. Eds., Asian Vegetable Research and Development Center, Shanhua, Taiwan. pp. 331–336

Hinds, W. E. (1918). Sweet potato root borer. *Ala. Agr. Expt. Sta .Cir*. 37, 8 pp.

Ho, T.H., (1970). "Studies on some major pests of sweetpotatoes and their control," *The Malaysian Agril. J*. **47**(4): 437–452.

Huang, P.C. (1982). Nutritive value of sweet potato. In AVRDC, ed. Sweet potato. Proceedings of the First International Symposium. Taiwan. University of Dhaka. Institute of Nutrition and Food Science. 1977. Nutrition survey of rural Bangladesh 1975-76, Dhaka. pp. 35-36.

Jackai, L.E. Sosinski, B., Jackson D.M. (2006). *"Occurrence and intra-specific variation of sweet potato weevil (Brentidae: Coleoptera) in relation to its potential Agriculture.* **14**(5): 257-282.

Jansson, R. K., Bryan, H. H., and Sorensen, K. A. (1987). "Within-vine distribution and damage of sweet potato weevil, *Cylas formicarius, elegantulus* (Coleoptera: Curculionidae), on four cultivars of sweetpotato in southern Florida," The Florida Entomologist. **70**(4): 523–526.

Kapinga, R., Mtunda, K., Chillosa, D. and Rees, D. (1997). "An assessment of damagetraded fresh sweetpotato roots," in Roots and Tuber Crops Research Programme, Progress Report for 1996, Mwanza, Ed., Research and Training Department, Ministry of Agriculture and Co-Operatives, Dares Salaam, Tanzania.

Kawochar, M.A., Mohanta, H.C., Hossain, M.A., Goswami, B.K and Uddin, M.J. (2014). Diversity of tuber crops in Bangladesh. Conference: Conference: 9th Biennial Conference of Plant Breeding and Genetic Society of Bangladesh, At KIB Auditorium, Dhaka, Bangladesh.

Kemner, N.A. (1924). The Sweet Potato Weevil, *Cylas formicarius*, in Java and the neighbouring Islands of the East Indies. *Zeitschrift fur Angewandte Entomologie.* **10**: 398-435.

Korada, R.R., Naskar, S.K., Palaniswami, M.S. and Ray, R.C. (2000). "Management of sweet potato weevil [*Cylas formicarius* (Fab.)]: an overview," *J. of Root Crops*. **36:** 14–26.

Ladányi, M. and Hufnagel, L. (2006). "The effect of climate change on the population of Sycamore lace bug (Corythucaciliata, say, tingidaeheteroptera) based on a simulation model with phenological response," *Appl. Ecol. and Environmental Res*. **4**(2): 85–112.

LeConte, J.L. and Horn, G.H. (1876).Technical description and distribution. *Amer. Philos. Soc. Proc*. **15:** 327.

Lima, M. and Morales, A. (1992). *Estudios Comparativos de Clones Precoces de Boniato [Ph.D. thesis]*, University "Marta Abreu" of Las Villas.

Maynard, D.N., Hochmuth, G.J., Lamberts, M.L. (1992). Sweet potato Production in Florida. A. Swindale, Measurement of the Economic Importance of Sweet potato Weevil, International Potato Center, Lima, Peru.

Nderitu, J., Silai, M., Nyamasyo, G. and Kasina,M. (2009). "Insect species associated with sweet potatoes (*Ipomoea batatas* (L.) Lam) in Eastern Kenya," *International Journal of Sustainable Crop Production.* **4**(1): 14–18.

Newell, W. (1917). Sweet potato root weevil. Fla. State Plant Bd. *Quar.Bui*. **2**(1): 81-100.

Nottingham, S.F., Son, K.C., Wilson, D.D., Severson, R.F. and Kays, S.J. (1989). “Feeding and oviposition preferences of sweet potato weevil, *Cylas formicarius* elegantulus (Summers), on storage roots of sweet potato cultivars with differing surface chemistries,” *J. of Chemical Ecol*. **15**(3): 895–903.

Okonya J.S. and Kroschel, J. (2013). “Incidence, abundance and damage by the sweet potato butterfly (Acraeaacerata Hew. and the African sweet potato weevils (*Cylas spp*.) across an altitude gradient in Kabale district, Uganda,” *International J. of Agri. Sci*. **3**(11): 814–824.

Olivier, G.A. (1807). Technical description. *Ent. Hist. Natr. Insect*. **5**:84.

Onwueme, I.C. and Charles, W.B. (1994). “Tropical root and tuber crops: production, perspectives and future prospects,” FAO Plant Prod Prot Paper 126:129, Food and Agriculture Organization of the United Nations, Rome, Italy.

Pierce, W.D. (1918). Weevils which affect Irish potato, sweet potato, and yam. *J. Agri. Res*. **12**(9): 604-610

Pillai, K.S. and Palaniswami, M.S. (1984). Pests of tuber crops. *Indian Farming*. **33**: 58-66.

Rajamma, P. and Padmaja, G. (1981). Annual Report, Central Tuber Crops Research Institute, Trivandrum, India.

Rajamma, P. (1983). “Biology and bionomics of sweet potato weevil, *Cylas formicarius* Fabr,” *in Proceedings of the Symposium on Insect Ecology and Resource Management*, Goel, S.D. Ed., Sanatan Dharm College, Muzaffarnagar, India. pp. 87–92.

Rao, R.K. (2005). “Systems approach for management of insect pest problem in tuber crops by farmers of Meghalaya,” CTCRI News. **22:** 3–4

Sherman, M. and Tamashiro, M. (1954) The sweet potato weevils in Hawaii their biology and control. *Hawaii Agricultural Exp Station Technical bull. No* 23.

Sherman, M. and Tamashi, M. (1954). The Sweet potato Weevils in Hawaii, their Biology and Control, Hawaii Agricultural Experiment Station, University of Hawaii.

Smit, N.E.J.M. (1997). "The effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweet potato weevil in Uganda," *Agriculture, Ecosystems and Environment*. **64**(3):191–200.

Smith, N. and Odongo, B. (2002). Integrated Pest Management for Sweet potato in East Africa, International Potato Center (CIP), Lima, Peru.

Son, K. C., Severson, R. F., Arrendale, R. F. and Kays, S. J. (1990). "Surface chemical differences between sweet potato lines with varying levels of resistance to the sweet potato weevil," *J. of the American Society for Hort. Sci*. **115**(4): 696–699.

Sorensen, K.A. (2009). Sweet potato Insects: Identification, Biology and Management, *The Sweet potato*. pp 161-188. spread in southern United States of America and the Caribbean," in ISHS *Acta Horticulturae* 703: II International Symposium on Sweet potato and Cassava: Innovative Technologies for Commercialization, International Society for Horticultural Science, Leuven, Belgium. p. 197–204.

Suenaga, T., Setokuchi, O. and Sakae, K. (1987). "Distribution of the sweet potato weevil *Cylas formicarius* Fabricius and the small sweet potato weevil, *Euscepes Postfasciatus* Fairmaire in the Amami Islands," *Kyushu Plant Protection Research*. **33**: 116–118.

Summers, S.V. (1875).The sweet potato root borer. *Home and J.* **10**(26): 401.

Sutherland, J.A. (1986)."Damage by *Cylas formicarius* Fab. To sweet potato vines and tubers, and the effect of infestations on total yield in Papua New Guinea," *Tropical Pest Management*. **32**(4): 316–323.

Sutherland, J.A. (1986). A review of the biology and control of sweetpotato weevil *Cylas formicarius* (Fab.) *Tropical Pest Management* **32**: 304-315.

TACTRI/COA (2014). Taiwan Agricultural Chemicals and Toxic Substances Research Institute Council of Agriculture.*Sweet potato Healthy Management Technique and Operation Manual*.

Takelar, N.S., (1982). A search for sources of resistance to sweet potato weevil. In R.L. Villareal and T.D. Griggs, (Eds), Sweet potato Proc.First Intl. Symp. *Asian Veg. Res. Dev*. Ctr., Shanhua, Taiwan, pp 147-156.

Teli, V.S. and Salunkhe, G.N. (1996). "A search for sources of resistance to sweet potato weevil. I. Morphological traits,"*J. of Maharashtra Agril. Uni*. **20:** 400–403.

Uritaini, I., Saito, T., Honda, H. and Kim, W.K. (1975). "Induction of furano terpenoids in sweet potato roots by the larval components of the sweet potato weevils," Agricultural and Biological Chemistry. **37**: 1875–1862.

USEPA. (2003). United States Environmental Protection Agency. *Strategic Plan for Pest Management Research & Education in Southern Sweet potato Production Systems.* Weevil, *Formosa Govterment research institute*. **62**: 1-35.

Woolfe, J. A. 1992. Sweet potato: An untapped food resource. Cambridge University Press, Cambridge, England.

CHAPTER VII

APPENDICES

Appendix I. Larval mortality of sweet potato weevil in laboratory condition

Month	Number of hatched larvae/5 selected fruit	Number of formed pupae/5 selected fruit	Percent of larval mortality
July	109	98	10.09
August	115	102	11.30
September	122	104	14.75
October	102	83	18.63
November	127	106	16.54
(Mean ±SD)	115±9.974	98.6±9.208	14.262±3.559

Appendix II. Number of pupa, adult emerged and percent of pupal mortality of sweet potato weevil in laboratory condition

Month	Number of formed pupae/5 selected fruit	Number of emerged adults/5 selected fruit	Percent of pupal mortality
July	106	93	12.26
august	104	90	13.46
September	98	81	17.35
October	102	78	23.53
November	83	67	19.23
(Mean ±SD)	98.6 ±9.208692	81.8 ±10.32957	17.166±4.544164

Appendix III. Average room temperature and humidity during the study period

Month	Average temperature	Average humidity
July	29	82
August	29	81
September	28	79
October	26	65
November	22	74