"BIOLOGY AND BEHAVIOURAL STUDIES OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E. SMITH) (LEPIDOPTERA: NOCTUIDAE) ALONG WITH ITS BIORATIONAL MANAGEMENT ON KHARIF MAIZE CROP."

M.Sc. (Ag) Thesis

by

Sneha Tiwari

DEPARTMENT OF ENTOMOLOGY

COLLEGE OF AGRICULTURE

FACULTY OF AGRICULTURE

INDIRA GANDHI KRISHI VISHWAVIDYALAYA

RAIPUR (Chhattisgarh)

2020

“BIOLOGY AND BEHAVIOURAL STUDIES OF FALL ARMYWORM *Spodoptera frugiperda* (j.e. SMITH) (LEPIDOPTERA: NOCTUIDAE) ALONG WITH ITS BIORATIONAL MANAGEMENT ON KHARIF MAIZE CROP.”

Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.)

by

Sneha Tiwari

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science
in
Agriculture
(ENTOMOLOGY)

U.E. ID. 20141519156 **ID. No. 120118113**

AUGUST, 2020

CERTIFICATE – I

This is to certify that the thesis entitled **"Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera:Noctuidae) along with its biorational management on kharif maize crop"** submitted in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Sneha Tiwari** under my/our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigations have been duly acknowledged by her.

Chairman

Date: 18-08-2020

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Chairman	(Dr.(Smt.) Sonali Deole)	
Member	(Dr.(Smt.) J. L. Ganguli)	
Member	(Dr. A. S. Kotasthane)	
Member	(Dr.(Smt.) G. Chandrakar)	

CERTIFICATE – II

This is to certify that the thesis entitled **"Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera:Noctuidae) along with its biorational management on kharif maize crop"** submitted by **Sneha Tiwari** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture** in the **Department of Entomology** has been approved by the external evaluator and student's advisory committee after oral examination, under the chairmanship of head of the Department.

for Signature of Head of the Department
(Dr. D. K. Rana)

Date :- 21-09-2020

Major Advisor ____________________

Faculty Dean ____________________

Approved/Not approved

Director of Instructions ____________________

ACKNOWLEDGEMENT

I take this golden opportunity to express my heartfelt sense of gratitude to all those, who guided and helped me to make my research possible. These words are small acknowledgement but never fully recompensed for their guidance, help and co- operation.

I start in the name of God who has bestowed upon me all the physical and mental attributes that I possess and skills to cut through and heal a fellow human.

I take this golden opportunity to express my deepest sense of gratitude to the Chairman of my Advisory Committee Dr. (Smt.) Sonali Deole, Associate professor, Department of Entomology, for her research insight, valuable guidance, constant encouragement, unique supervision and kind sympathetic attitude, despite her heaviest schedule of work, her helpful, patience, creative guidance has given touch of excellence to this manuscript.

I express my sincere and profound gratitude to Dr. D. K. Rana, Head of Department of Entomology, College of Agriculture, Raipur, for his inspiring suggestions and providing me all the necessary facilities during my research work.

I have immense pleasure in expressing my whole hearted sense of appreciation for the other members of my Advisory Committee Dr.(Smt.) J. L. Ganguli, professor, Department of Entomology, Dr. A.S. Kotasthane, professor, Department of Plant Pathology, Dr.(Smt.) Gayatri Chandrakar, professor, Department of Agril. Statistics, Mathematics and Computer Science for their guidance, suggestions and encouragement during the course of investigation.

I wish to record my sincere and greatful thanks to Dr. S. K. Patil, Hon'ble Vice Chancellor, Dr. M. P. Thakur, Director of Instructions, Dr. R. K. Bajpai, Director Research Services, Dr. S. C. Mukherjee, Director Research Services, Dr.G. K. Shrivastava, Dean Student Welfare and Dr. S. S. Rao, Dean, College of Agriculture, IGKV, Raipur for their administrative and technical help, which facilitated my research work.

I am thankful to the teachers of my department Dr. Rajeev Gupta, Dr. A. K. Dubey, Dr. S. S. Shaw, Dr. H. K. Chandrakar, Dr. Sanjay Sharma, Dr. B. P. Katalam, Dr. Gajendra Chandrakar, Dr. Vikash Singh for their constant co-operative suggestion, encouragement and help during my investigation.

I would like to express my sincere gratitude to Dr. M. Pandey, U. K. Watti and Library staffs for giving me their kind help during my present study.

I do express my thanks to the non-technical staff members namely, Tribhuvan Sahu, Dinesh Kumar Sahu, Parasram Rangier, Kunjlal Sahu, Devnarayan Chardrakar, who were always ready to help me during the period of study.

I am deeply priviledged to express heartfelt thanks to my friends, Mamta Bhagat, Tamraj Chandrakar, Rajkumari Sidar, Jharna Chaturvedani, Anisha Shrivastava, Madhu Painkra, Sheikh Alisha, Ashish Kumar Gupta who provided me an inner strength and guided me during my entire academic career as to steer up my ambition in a proper way.

For the most important personalities of my life, there aren't enough words to express my gratitude to my beloved father Shri Pramod Tiwari, mother Smt. Rajeshwari Tiwari, my elder brother Dr. Avinash Tiwari and my younger brother Abhishek Tiwari for their encouragement, sincere prayer and blessings which have always been the most vital source of inspiration and motivation in my life.

I would like to convey my cordial thanks to all those unmentioned persons who helped me directly and indirectly to fulfil my dream come true.

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Date : 21-09-2020

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Notation	Description
@	At the rate
%	Per cent
$\leq$	Less than or equal to
$\geq$	More than or equal to
$<$	Less than
$>$	More than
$=$	Equal to
℃	Degree celcious

LIST OF ABBREVIATIONS

FAW	Fall armyworm
et al.	And others/ co-workers
Fig.	Figure
ha^{-1}	Per hectare
Hrs	Hour
Kg	Kilogram
Cm	Centimeter
g	Gram
$Plant^{-1}$	Per plant
B: C ratio	Benefit cost ratio
No.	Number
NS	Non-significant
m^2	Square meter
Q	Quintal
Rs.	Rupees
SMW	Standard Meteorological Week
SEm ±	Standard error of mean
CD	Critical difference
i.e.	That is
Viz.	Namely
Wt.	Weight
DOS	Date of sowing
DAS	Days after spray
DAT	Days after treatment

THESIS ABSTRACT

a) Title of the Thesis :	Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera:Noctuidae) along with its biorational management on kharif maize crop.
b) Full name of the student :	Sneha Tiwari
c) Major Subject :	Entomology
d) Name and Address of the Major Advisor :	Dr.(Smt.) Sonali Deole Department of Entomology College of Agriculture, Raipur (C.G.)
e) Degree to be Awarded :	M.Sc. (Ag.)

Signature of the student

Signature of Major Advisor

Date: 21-09-2020

Signature of Head of the Department

ABSTRACT

The present analysis entitled **"Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) along with its biorational management on kharif maize crop"** was conducted during July to November, 2019 at the Bio-control laboratory and Research cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya; Raipur (C.G.)

The biology of fall armyworm was studied on three different genotypes of maize crop *viz.* fodder corn(African tall), sweet corn (Sugar-75) and hybrid corn (PRO-4212) and it was found that the external appearance was similar for all the stages of the pest but the incubation period ranged from 1.90 ± 0.10 days, 2.00 ± 0.00 days and 2.90 + 0.10 days, total larval period was observed as

16.25 ± 0.17, 16.65 ± 0.16 and 20.25 ± 0.29 days, pupal stage was observed 6.65 ± 0.22, 6.30 ± 0.14 and 6.95 ± 0.15, longevity of adult female was observed 9.15 ± 0.19, 9.05 ± 0.19 and 9.20 ± 0.22 days, while in male adult 6.20 ± 0.11, 6.15 ± 0.13 and 6.60 ± 0.13 days, where the selected hosts were fodder corn, sweet corn and hybrid corn, respectively.

The study of ovipositional preference behaviour showed that the female moth of fall armyworm principally preferred lower surface of leaf for their egg laying. Study of neonate feeding preference behaviour resulted that the order of preference of host was hybrid corn< fodder corn< sweet corn. The study of larval dispersal behaviour resulted that the neonate were feeding in same position till 12 hrs after hatching and then begins to move to the upper surface from the lower surface of leaf. By 2^{nd} and 3^{rd} instar, the larvae were completely taken apart and later instars were move permanently into whorl. The study of cannibalism behaviour of fall armyworm resulted that the maximum percent of cannibalism was found 66.6 ± 0.00 percent, when three larvae of fourth, fifth and sixth instar were noticed. The study of mating behaviour resulted that the duration of copulation was varied from 42 to 73 min with an average of 57.60 ± 3.49 min.

During learning period parasitoids of fall armyworm, *viz*. *Chelonus sp.* (Hymenoptera: Braconidae), *Cotesia sp.* (Hymenoptera: Braconidae), *Bracon sp.* (Hymenoptera: Braconidae), *Meteorus sp.* (Hymenoptera: Braconidae), *Ischiodon scutellaris* (Diptera: Syrphidae), *Buquetia musca* (Diptera: Tachinidae), *Helophilus sp.* (Diptera: Syrphidae), *Phaonia sp*. (Diptera: Muscidae) were recorded and among them, *Cotesia sp.* was prominent.

Bio- efficacy of eight bio-rational insecticides against fall armyworm was assessed, among which Spinetoram 11.7% SC @ 0.3 ml/l was found to be the most effectual chemical, recorded the highest larval percent reduction *i.e.* 79.48 percent after first spray, 85.78 percent after second spray and 46.74 percent after third spray with cost benefit ratio (1: 4.98) followed by Chlorantraniliprole 18.5% SC @ 3.0 ml per lit with larval percent reduction 56.89 percent after first spray, 58.65 percent after second spray and 39.07 percent by third spray with the cost benefit ratio (1: 3.45).

शोध सारांश

(अ) शोध शीर्षक : "फॉल आर्मीवॉर्म, *स्पोडोप्टेरा फ्रुजीपरडा* (जे. ई. स्मिथ) (लेपीडोप्टेरा : नॉक्टुइडी) के जीव विज्ञान और व्यवहार संबंधी अध्ययनों के साथ–साथ खरीफ मक्का की फसल पर इसके जैव–तार्कसंगत प्रबंधन"

(ब) विद्यार्थी का पूरा नाम : स्नेहा तिवारी

(स) मुख्य विशय : कीट विज्ञान

(द) मुख्य सलाहकार का नाम व पता : डॉ. सोनाली देवले, कीट विज्ञान विभाग, कृषि महाविद्यालय रायपुर (छ0ग0)

(इ) सम्मानित किये जाने वाले उपाधि: एम.एस.सी. (कृषि)

विद्यार्थी का हस्ताक्षर

मुख्य सलाहकार का हस्ताक्षर

दिनांक 21-09-2020

विभागाध्यक्ष के हस्ताक्षर

सरांश

वर्तमान शोध शीर्षक "फॉल आर्मीवॉर्म, स्पोडोप्टेरा फ्रुजीपरडा (जे.ई. स्मिथ) (लेपीडोप्टेरा : नॉक्टुइडी)के जीव विज्ञान और व्यवहार संबंधी अध्ययनों के साथ–साथ खरीफ मक्का की फसल पर इसके जैव–तार्कसंगत प्रबंधन" को इन्दिरा गॉधी कृषि वि"वविद्यालय रायपुर (छ0ग0) के जैव नियंत्रण प्रयोग"ााला एवं अनुसंधान सह अनुदे"ाक प्रक्षेत्र में जुलाई से नवम्बर 2019 के दौरान आयोजित किया गया।

फॉल आर्मीवॉर्म के जीव विज्ञान के अध्ययन हेतु मक्का की फसल के तीन अलग–अलग जीनोटाईप यथा– चारा मक्का (अफ्रीकन टाल), स्वीट कॉर्न (शुगर–75) और संकर मक्का (प्रो–4212) का चुनाव किया गया और यह पाया गया कि प्रत्येक जीनोटाईप में पोषित कीट की सभी अवस्थाएं, बाह्य दिखावट एवं आकारिकी में समान थे, किन्तु चारा मक्का, स्वीटकॉर्न तथा संकर मक्का में उष्मायन अवधि क्रमशः – 1.90 ± 0.10, 2.00 ± 0.00 तथा 2.90 ± 0.10 दिन, लार्वल अवधि क्रमशः – 16.25 ± 0.17, 16.65 ± 0.16 तथा 20.25 ± 0.29 दिन, कोशित अवधि क्रमशः– 6.65 ± 0.22, 6.30 ± 0.14 तथा 6.95 ± 0.15 दिन, वयस्क महिला शलभ की दीर्घायु क्रमशः 9.15 ± 0.19, 9.05 ± 0.19 तथा 9.20 ± 0.22 दिन, जबकि वयस्य पुरूष शलभ की दीर्घायु क्रमशः 6.20 ± 0.11, 6.15 ± 0.13 तथा 6.60 ± 0.13 दिन पायी गई।

अण्डे देने हेतु स्थान चुनाव की प्राथमिकता के व्यवहार के अध्ययन से यह पता चलता है कि फॉल आर्मीवॉर्म की मादा शलभ मुख्य रूप से अपने अण्डे देने हेतु पत्तियों की निचली सतह का चुनाव करती है। नवजान इल्लियों के भोजन प्राथमिकता व्यवहार के अध्ययन के परिणामस्वरूप चयनित मेजबान की वरीयता का क्रम संकरा मक्का < चारा मक्का < स्वीट कॉर्न था। इल्लियों के वितरण व्यवहार के अध्ययन से यह पाया गया कि, नवजात इल्लियां अण्डे से निकलने के पश्चात 12 घंटे तक एक ही स्थान पर पत्तियों को खाती हैं, तत्पश्चात पत्तियों की निचली सतह से उपरी सतह पर जाना प्रारंभ करती हैं। दूसरे और तीसरे निरूप तक इल्लियां पूरी तरह से वितरित हो जाती हैं, और बाद के निरूप स्थायी रूप से पर्ण चक्रक में स्थानांतरित हो जाती हैं। नर भक्षण व्यवहार के अध्ययन के परिणामस्वरूप अधिकतम नर भक्षण प्रतिशत चौथे, पॉचवें और छठे निरूप के मध्य,66.6 ± 0.00 प्रतिशत पाया गया। संभोग व्यवहार के परिणामस्वरूप मैथुन की अवधि 42 से 73 मिनट, औसतन 57.62 ± 3.49 मिनट दर्ज की गई।

अध्ययन अवधि के दौरान फॉल आर्मीवॉर्म के परजीवियों के रूप में , चेलोनस स्पी. (हाइमेनोप्टेरा : ब्रैकोनिडे), कोटेसिया स्पी. (हाइमेनोप्टेरा : ब्रैकोनिडे), ब्रैकान स्पी. (हाइमेनोप्टोरा : ब्रैकोनिडे), मेटोरस स्पी. (हाईमेनोप्टेरा : ब्रैकोनिडे), इस्चियोडोन स्कुटेलारिस (डिप्टेरा : सिरफिडी), बुक्केटिया मस्का (डिप्टेरा : टैचिनीडे), हेलोफिलस स्पी. (डिप्टेरा : सिरफिडे), फोनिया स्पी. (डिप्टेरा : मस्किडे) दर्ज किए गए, जिनमें कोटेसिया स्पी. प्रमुख था।

मक्का की फसल (प्रो–4212) में फॉल आर्मीवॉर्म के खिलाफ आठ जैव–तर्क संगत कीटनाशकों की जैव–प्रभावकारिता का मुल्यांकन किया गया, जिसमें स्पिनेटोरम 11.7% एस सी @ 0.3 मिली/ली. सबसे प्रभावी रसायन पाया गया, जिसमें इल्लियों के प्रतिशत में सर्वाधिक कमी यथा– पहले छिड़काव के पश्चात 79.48 प्रतिशत, दूसरे छिड़काव के पश्चात 85.78 प्रतिशत तथा तीसरे छिड़काव के पश्चात 46.74 प्रतिशत दर्ज की गई। इस रसायन का लागत लाभ अनुपात (1 : 4.98) पाया गया, जो सर्वाधिक था। दसरे प्रभावी रसायन के रूप में क्लोरेंट्रानिलिप्रोएल 18.5% एस.सी. @ 3.0 मिली/ली, जिनमें इल्लियों के प्रतिशत में कमी क्रमशः पहले छिड़काव के पश्चात् 56.89 प्रतिशत, दुसरे छिड़काव के पश्चात् 58.65 प्रतिशत एवं तीसरे छिड़काव के पश्चात 39.07 प्रतिशत और लागत लाभ अनुपात (1 : 3.45) दर्ज किया गया।

CHAPTER I
INTRODUCTION

Maize, *Zea mays* L. is a member of the family: Poaceae also known as corn. It is one of the most flexible growing crop with greater adaptability to different agro-climatic conditions. Because of higher genetic yield potential among the cereals, this crop is globally popular as the "Queen of cereals" (Jeyaraman, 2017).

In around 5,000 BC, the maize crop was originated in central Mexico. It is the day neutral, cross pollinated and C4 plant. Maize is an economically important cereal crop among the various cereals cultivated, which is generally cultivated in tropical as well as in sub-tropical parts of the world. Leafy stalks of maize produces ears, which contains the grain and called as kernels or seeds. The kernels of maize are most commonly used as starch in cooking. The six major types of maize (corn) are dent corn, pod corn, flint corn, popcorn, flour corn, and sweet corn (Smith, 2013).

The maize crop constitutes as staple food in so many regions of the world. It is also important as fodder crop, particularly for milch animals. Maize contains around 72 per cent of starch, 10 per cent of protein, and 4 per cent of fat (Ranum *et al.,* 2014). Maize is rich in "Zein" protein but deficient in tryptophane and lysine. Immature maize shoots are able to accumulate a very powerful antibiotic substance *viz.* DIMBOA that serve as a natural protection against a wide variety of pest including insects, pathogenic fungi and bacteria.

The United States produces about 40 per cent of the world's harvest of maize; while other top producing countries include China, Brazil, Mexico, Indonesia, India, France and Argentina. Maize is the third most important food crop in India after rice and wheat accounting for about 20 per cent of the global area under cereals (FAO, 2005). India's main maize producing states, that contributes more than 80 per cent of the total maize production are Andhra Pradesh (20.9 %), Karnataka (16.5 %), Rajasthan (9.9 %), Maharashtra (9.1 %), Bihar (8.9 %), Uttar Pradesh (6.1 %), Madhya Pradesh (5.7 %), Himachal Pradesh (4.4 %).

In Chhattisgarh maize is mainly produced in 'Pathar' region (Plateau area) of Bastar district's and Surguja's hilly terrain during the kharif season. About 40 per cent of maize production comes from Kondagaon, Kanker and Baster district in the state. Currently, maize cultivation in Chhattisgarh is gaining importance especially in rainfed tracts due to its increasing demand as feed for animals and raw material for industry. Therefore, there is a need to explore the possibilities of increasing the productivity by better understanding of constraints in production of maize. Due to the alternatives of high yielding varieties and cultivability throughout the year, maize crop has become more popular among the farmers in recent year.

In 2017-18 the world maize production is estimated about 1,047 million metric tonnes, cultivated in 186 m ha area by International Grain Council Report. Among the countries United States of America was stood first in maize production with 371.52 million tonnes followed by China (256 mt), Brazil (94.50 mt), Europian Union (59.50 mt), Argentina (42.50 mt), and India (26.50 mt). In Chhattisgarh, it is cultivated on an area of 207.82 ha with 254.13 million tons of output and 1693 kg per hectare of productivity (Calendar, 2015-16).

Although about 139 insect pests cause varying degree of damage to maize crop, but only about a dozen of these are quite serious and require control measures, *i.e.* maize stalk borer, pink stem borer, and shoofly are the insects of national importance, while the armyworm, jassid, thrips, pyrilla, grasshopper, white grub, cut worm, hairy caterpillar, termite, and the leaf miner are more serious pest of regional level (NIPMP, 2001). Amongst all, Shoot fly, *Atherigona orientalis*, Maize stem borer, *Chilo partellus* Swimhoe and Pink stem borer, *Sesamia inferens* Wlaker are the most serious pest in India (Manjunath, 2013). In past few years a new pest fall armyworm became an invasive challenge across the world. However, the relatively high damage by fall armyworm is occasionally reported (Porter *et al*., 2000)

Fall armyworm, *Spodoptera frugiperda* (J.E.Smith) belongs to the order Lepidoptera and family Noctuidae is native to tropical and subtropical regions of the Americas. It was reported for the first time from the African continent, in Nigeria, Sao Tomé, Benin and Togo region (Goergen *et al*., 2016). In India, fall armyworm (FAW) was firstly reported in the research fields of maize at the University of Agricultural and Horticultural Sciences, Shimoga, Karnataka (Sharanabasappa *et al.*, 2018). In Chhattisgarh the *Spodoptera frugiperda* was first reported at Raipur (Deole and Paul, 2018).

The name "fall armyworm" originates by their nature of damage, where infestations sometimes resemble as an army, as they move across large agriculture fields and earned their common name by eat all plant matter and they encounter in their wide dispersals, like a large army (Smith, 1797). Due to its migratory behaviour the fall armyworm was known as a sporadic pest.

Fall armyworm causes economic losses in so many crops, such as maize, cotton, soybean and beans (Pogue, 2002; Nagoshi *et al*., 2007; Bueno *et al.,* 2010). In maize, fall armyworm attacks in all stages of the plant, from seedling until tasseling and causing defoliation, killing young plant, resulting in grain damage and subsequently reduces quantity and quality of yield (Peairs and Sanders, 1979). Their damage appears as ragged-edged holes on leaves and tassels. Severe feeding by FAW, may give the appearance of corn that has been damaged by hail. When outbreak takes place, the severity of the problem is compounded by the ability of FAW to damage a range of vegetative to reproductive plant structures, creating the opportunity to cause devastating crop losses (Jarron *et al*., 2015). The recent studies conducted by Center for Agriculture and Bioscience International (CABI), which was done in 12 maize-producing African countries showed that without proper management, FAW can cause maize yield losses ranging from 8 – 21 million tonnes.

Biology and behaviour are the primer that provides us the needed informative background of related pests, which helps in their efficient management. So, the study of biology of FAW as occurring in India is very much important for identifying the life stages and also for planning IPM strategies. The more we know about their biology and behaviour, including their natural enemies, the more likely we will able to manage them effectively. We also know that the indiscriminate use of chemical pesticides has caused many serious problems including genetic resistance of pest species, harmful residues, increased application costs, contamination of the environment and hazards; hence there is a need to use biorational insecticides.

Keeping all these in view, the present study entitled **"Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) along with its biorational management on kharif maize crop"** and under these title following objectives were taken:-

Objectives of investigation -

1. ***In vitro*** **studies on the biology and behaviour of fall armyworm on maize crop.**
2. **Studies on parasitoids of different stages of fall armyworm in laboratory conditions.**
3. **Relative efficacy of different bio-rational insecticides against fall army worm on maize crop.**

CHAPTER-II
REVIEW OF LITERATURE

A brief review on the present investigation entitled **"Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera : Noctuidae) along with its biorational management on kharif maize crop"** was presented under following aspects:

2.1 *In vitro* studies on the biology and behaviour of fall armyworm on maize crop.

Pitre *et al.* (1983) evaluated 8 species of crop plant for egg-laying preference of fall armyworm, *Spodoptera frugiperda* (J.E. Smith), in which mainly rye grass, sorghum, maize and wheat crops were mostly favored, while soybean and cotton crops were the slightest favored host. About 54 to 64 days elder and larger maize, cotton, sorghum and soybean plants were strongly chosen for the egg deposition as compared with the younger and smaller plants of 22 to 42 days. Egg masses concentrated on leaves (between nodes) were observed about 4 to 9 with an average of 7.1 on maize, 3 to 9 with an average of 6.1 on sorghum, 5 to 9 with an average of 7.7 on cotton and 4 to 9 with an average of 6.3 on soybean. For the egg laying, the lower surface of leaves of each of the above crop were preferred over the upper surface of leaves, which was recorded 100 percent for the cotton and soybean crop, 92 percent for sorghum and 70 percent for corn crop.

Harrison (1986) observed the behaviour of feeding as well as oviposition preference of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize crop, *Zea mays* at the stage of whorl formation. They evaluated that, just after the hatching of eggs, the infestation was unclear for some times and the larvae moved from plant to plant until they become adult moths. Neonates were fed in whorls first and ultimately become large enough for their feeding to be understandable. The number of plants becoming infested by each egg mass was somewhat depend on egg density. In the observed plot, density of egg mass varied from 5 to 20 in per 100 plants while the number of plants damaged by larvae was varied from 5.16 to 30.6.

Raffa (1987) observed that the fall armyworm, *Spodoptera frugiperda* (J.E. Smith), which is a polyphagous pest of many crops, showed inferior rates of cannibalism in corn than red kidney bean.

Simmons *et al.* (1992) examined the mating behaviour in fall armyworm, *Spodoptera frugiperda* (J. E. Smith) in the laboratory condition. They were observed the mating pairs of male and female moths throughout the night and resulted that, most of the mating (80%) lasted longer than 45 min. and the mean period of copulation (mating) averaged of 130 min. Female moths of fall armyworm copulated 0 to 11 times with an average of 3.7 times throughout their life span, although the male moths copulated with a range of 0 to 15 times with an average of 6.7 times.

Chapman *et al.* (1999) carried out an experiment to examine the occurrence of cannibalism during the larval period of a noctuid moth, *Spodoptera frugiperda* and noticed that cannibalism was observed frequently even when food was not limiting but occurred more frequently at low food quantities and/or high rearing densities. In the incidence of cannibalistic behaviour, the sex of the larvae had no effect; however probably the larval stage can affect the occurrence of cannibalism. Among 5th and 6th instar larvae, the incidence of cannibalism was significantly higher than the earlier instars, and larvae were more preferred to consume younger conspecifics than larvae of the similar age.

Chapman *et al.* (2000) observed the behaviour of cannibalism at larval stage of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on maize crop in field condition, which was examined by the help of field cages. The cannibalism behaviour was found to account for around 40 percent mortality when maize plants were infested with two or four 4th instar larvae.

Meagher *et al.* (2011) studied about the ovipositional preference in fall armyworm, *Spodoptera frugiperda*. To illustrated observations of host fidelity in the field, two greenhouse bioassays were used to access the ovipositional preference behaviour of the two strains of corn, *Zea mays*. In first bioassay, female moths placed more masses of eggs on the screen enclosure than on corn plants. In the second bioassay, where corn, *Zea mays* and grass *Cynodon dactylon* were used to access the ovipositional preference behaviour, it was observed that females placed an equal number of egg masses on corn and grass plants. As a part of egg mass individual eggs were also counted on plants as well as on the screen enclosure. The females of corn strain equally placed eggs on both, host plant as well as in screen enclosures. This was the first reliable report of oviposition behaviour of fall armyworm females.

Vilarinho *et al.* (2011) observed that the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is one of the most important maize pests in the Americas and particularly in South America. They evaluate the dispersal capacity of adults of *S. frugiperda*.

Pannuti *et al.* (2015) studied about the larval movement and feeding behaviour of *Spodoptera frugiperda* on reproductive stages as compared to vegetative corn stages. Thus, they divided the corn plant in four zones *viz.* tassel, above ear, ear zone, and below ear to examine on-plant larval movement and resulted that the ear zone has a strong effect on feeding choice and survival of fall armyworm larvae regardless of reproductive corn stage. Feeding site choice is made by first-instar. Corn leaves of reproductive plants were not suitable for early instar development, but silk and kernel tissues had a positive effect on survival and development of fall armyworm larvae on reproductive stage corn. They also worked on the effect of different corn tissues *i.e.* opened tassel, closed tassel, silk kernel and leaf and two feeding sequence scenarios *i.e.* closed tassel-leaf-silk-kernel and leaf-silk-kernel on larval survival in lab condition.

Silva *et al.* (2016) studied on the development of *Spodoptera frugiperda*, by using different food sources in the laboratory as well as in field. In their experiment the newly hatched larvae were fed in soybean, maize, wheat, cotton and oat's leaves. An artificial diet was also used as control and the duration of pre-pupal, pupal and larval-adult period were recorded. Apart from that pupal weight, sex ratio, survival percentage, larva feeding preference, oviposition preference and nutritional quality of various hosts were also recorded. By the investigation it was resulted that, the larvae fed on wheat showed the shortest larva-adult period and which were fed on the cotton and soybean had the longest larval development cycles but lowest pupal weight. When nutritional variables were examined, treatments influenced the insect growth, food consumption and digestion and it was noted that the grasses were better hosts for the development of *S. frugiperda,* while cotton was the least favored food followed by soybean.

Piracicaba (2017) studied on development of the S*podoptera frugiperda* (J.E. Smith), in different food sources in the laboratory as well as in field condition and observed the feeding preference of the pest. Many crops were taken for the experiment and it was reported that the neonates were preferred the leaves of soybean, cotton, maize, wheat, and oat for their feeding. Duration of pre-pupal, pupal, and larvae- adult period, pupal weight, sex ratio, survival rate, feeding preference of larvae, ovipositional preference and nutritional quality of different hosts were also studied.

Assefa (2018) reported that, during warm weather the entire life cycle of fall armyworm, Spodoptera frugiperda is completed in 30 days and it can take up to 90 days at cool weather. He also worked on the egg laying preference and observed that the eggs are generally laid at the underside of leaves. Total production of eggs per female is around 1500, with a maximum production of over 2000.

Igyuve *et al.* (2018) evaluated the biology and impact of fall armyworm, S*podoptera frugiperda* (J.E. Smith) on maize production. According to them the egg of fall armyworm was about 0.3 mm in length and 0.4 mm in diameter. The number of eggs per mass varies significantly but was often between 100 and 200 and the total production of eggs per female averages approximately 1500 with a maximum production of over 2000. The length of larval period appears to be about 14 days in summer and about 30 days in the cool weather. The duration of pupal period was about 8 to 9 days during the rainy season but the duration reaches up to 20 to 30 days in the season of winter. The adult lifespan was estimated about 10 days on an average, with a variation of around 7 to 21 days.

Sharanabasappa *et al.* (2018) evaluated the life history of fall armyworm, *Spodoptera frugiperda* (J. E. Smith). The experiment was conducted under the laboratory condition during June to July 2018 at Shimoga, Karnataka. By the experiment, it was noted that the gravid female moth lay the eggs with the fecundity of 1064 eggs. Incubation period, total larval period and pupal period were observed to be ranges from 2 to 3, 14 to 19 and 9 to 12 days, respectively. The total lifespan of male and female was noted to be 32 to 43 and 34 to 46 days, respectively.

Deole and Paul (2018) first time recorded the infestation level of fall armyworm, *Spodoptera frugiperda* on maize variety J- 1006, the population of larvae at vegetative stage was 25 in 200 Sq. m area indicating their preference on soft leaves of maize. They reported that the life cycle of fall armyworm was completed in about 28-35 days.

Nogueira *et al.* (2019) evaluated the ovipositional preference, growth, and survival rate of *S. frugiperda* on maize crop. The preference of oviposition was examined by using free and no-choice tests and by evaluating the insect growth parameters *viz.* weight, developmental time, survival in different stages of life cycle and nutritional indices. It was resulted that the landrace Perola and cultivar BRS-Caatingueiro were the least favored host for the oviposition by *S. frugiperda.* The larvae fed on landrace Perola, consumed very low amount of leaves and take longer time in development and lower survival rate until the end of the pupal stage. But overall, Perola was the most promising source of resistance to *S. frugiperda*.

Aditya and Singh (2019) conducted a survey and reported that, the fall armyworm *Spodoptera frugiperda* is notorious insect with high dispersal capability, wide host range and high fecundity, which make it one of the most severe economic pest. They also worked on the biology of this pest and resulted that the young larvae are difficult to identify morphologically as the early instars resemble those of several other noctuids. They also observed the behaviour of cannibalism among the larvae of *S. frugiperda* and reported that the sex of larvae had no effect on the occurrence of cannibalistic behaviour and the frequency of cannibalism was significantly higher among 5^{th} and 6^{th} instar larvae than among the earlier instars.

Prasanna *et al.* (2018) worked on the biology of *Spodoptera frugiperda* and resulted that the egg of FAW was 'dome' in shape, which measures 0.4 mm in diameter and 0.3 mm in height. They also observed that initially, at the time of oviposition the eggs were pale yellow to creamy in colour but they turned to light brown in colour before hatching.

Busal and Chapagain (2020) worked on the life cycle of fall armyworm (FAW) and reported that this pest completed the life cycle in four phases *viz*. egg, larva, pupa and adult. The pest required about 30 days in season of summer, 60 days in season of autumn and spring to complete its life cycle. However, in winter season this duration may be prolonged up to 80 to 90 days. They also noticed that the adult male moth was smaller than female moth. In investigation the female body length and wingspan were recoded of 1.7 cm and 3.8 cm, respectively, while the male body length and wingspan were recorded of 1.6 cm and 3.7 cm, respectively.

2.2 Studies on parasitoids of different stages of fall armyworm in laboratory conditions.

Ashley (1979) worked on total 53 species of parasitoids of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) and the parasitoids were reared from fall armyworm eggs and larvae. Out of 53 , only 18 species were common to the continental United States, while 21 species were present in south America and Central America including Mexico. From the experiment, it was resulted that *Chelonus insularis* and *Temelucha sp.* did not emerged from larvae having head capsule width of greater than 1.8 mm and *Apateticus marginiventris* did not emerged from the larvae with head capsule width greater than 1.2 mm.

Loke and Ashley (1983) studied on a parasitoid *i.e*. *Cotesia marginiventris* as potential kairomone source of fall the fall armyworm, *Spodoptera frugiperda* (FAW). The bioassay was done with females of Cotesia marginiventris Cresson in Petri dishes of 10 cm diameter. Mated females of *C. marginiventris,* ranging in age from 1 to 3 days exhibited the most intense bioassay responses to potential source of kiaromone. Parasitism rates were highest in larvae of 48 hrs old.

Wheeler *et al.* (1989) worked on parasitoids of all larval instars of the fall armyworm (FAW), *Spodoptera frugiperda* on maize crop during growing season and noted that overall. 42 percent of the host larvae were killed by the natural enemies. The braconid parasitoid, *Chelonus insularis* was the most common natural enemy accounting for 36.8 percent of the complex and responsible for about 15.5 percent mortality of larvae of fall armyworm. Some other important natural enemies of fall armyworm *viz.* nematode *Hexamermis sp*., tachinid *Lespesia sp*. and imperfect entomopatogenic fungus *Nomuraea rileyi*, *Chelonus insularis* were also recorded.

Turlings *et al.* (1990) worked on the *Cotesia marginiventris* Cresson, which is the parasitoid of fall armyworm and reported that the damaged seeding by fall armyworm are responsible to attract the females of *Cotesia marginiventris*. Frass and host larvae were the other important components of a plant-host complex were considerably less attractive than the damaged seedlings; frass alone was more attractive than larvae alone. The role of plants in the host-finding behaviour of parasitoids was also discussed.

Gross *et al.* (1991) conducted a laboratory as well as a field experiment based upon fall armyworm, *Spodoptera frugiperda* (J.E. Smith) and the result was that observed that the *Archytas marmoratus* and *Ophion flavidus* had the highest percentage natural parasitism on fall armyworm from late April to mid-June. The 4^{th}, 5^{th} and early 6^{th} instars of FAW were parasitized with equal success by *Ophion flavidus*, but were minimally successful in completing development on late 6th instar. In the 3rd, 4th, 5th and 6th instars, *A. marmoratus* were equally successful in completing their growth.

Chapman *et al.* (2000) conducted a field trial to inspect the effect of larval density on the occurrence of natural enemies of *S. frugiperda*. On maize plants with higher rates of larval feeding damage the abundance of predator's viz. earwigs, green lacewings, staphylinids and other predatory beetles was significantly greater, although the predator abundance relationship with the number of larvae of FAW was less evident per plant. Since larval damage was probably a more accurate measure of previous larval density than the number collected during an assessment, this was suggested that the risk of predation for larvae living in large group would be higher. In the experiment, it was noted that parasitism was responsible for 7.1 percent mortality of larvae in sorghum crop, in which 6 species of hymenoptera and tachinidae were involved. There was no influence of larval density or within plant distribution on the risk of larval attack by parasitoids. The selective advantages of cannibalism were also discussed, in contrast to the possibility of parasitism.

Ochoa *et al.* (2003) worked on parasitoids and parasites of fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith). The experiment was conducted by using references describing parasitized eggs, larvae, pupae and adult stages of fall armyworm were collected from different crops or habitats. Maize was the crop where the fall armyworm was collected more frequently followed by rice. By the experiment it was noted that *Chelonus insularis* Cresson, *Chelonus sp.* and *Euplectrus platyhypenae* Howard were the most appropriate parasitoids. Apart from that, *Archytas incertus* Macq., *Archytas marmoratus* Tns., *Chelonus insularis* and *Meteorus laphygmae* Viereck, *Diapetimorpha introita* Cresson were the most important parasitoids of pupal satge of fall armyworm. An acugutturid, *Noctuidonema guyanense* Remilllet & Silvain was also observed as a most important ectoparasitic nematode attacking on the adult of FAW and other noctuid moths.

Gonzelez *et al.* (2007) conducted a survey and observed for the first time some parasitoids of larval population of *Spodoptera frugiperda*, from a field of traditional maize crop. *Lespesia archippiyora* (Diptera: Tachinidae), *Winthemia sp.* (Diptera: Tachinidae), *Archytas* *marmoratus* (Diptera: Tachinidae) and *Eupletrus plathypenae* (Hymenoptera: Eulophidae) are the species of parasitoids, which were found during the survey.

Ramiro *et al.* (2009) conducted a survey on the parasitoids of Hymenoptera and Diptera, responsible for the parasitism of larvae of fall armyworm, Spodoptera frugiperda (J. E. Smith) to conclude their incidence and parasitism rates in Mexico. 251 larvae were developed parasitoids for an overall 20.1 percent of parasitism rate. Five braconids *viz.*, *Rogas vaughani* Muesebeck, *Rogus laphygmae* Viereck, *Chelonus insularis* Cresson, *Chelonus cautus* Cresson and *Glyptapanteles militaris* Walsh were recorded from the larvae of FAW. One eulophid *i.e. Euplectrus plathypenae* Howard as well as two ichneumonids, *viz. Neotheronia sp*. and *Ophion flavidus* Brulle were also recovered. Some dipteran parasitoids were also recovered from the last instars; these were the tachinids *i.e.*, *Archytas marmoratus* Towsend, *Winthemia sp*., *Archytas sp.* and *Lespesia archippivora* Riley. Dipteran parasitoids develoed 6.3 percent of parasitism and were mostly recovered from the 5th and 6th instars of FAW. Most of the parasitoids were recovered from the larvae of FAW which were obtained from maize plants. In the survey *Ophion flavids*, *Euplectrus plathypenae* and *Chelonus spp*. were the most often recovered species of parasitoides.

Murua *et al.* (2009) conducted a survey to know about the natural distribution of the fall armyworm, *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera: Noctuidae), to update the information of the occurrence of its complex of parasitoids. The larvae of *S. frugiperda* were collected from the maize plants from 9 localities. Total 30 plants of maize were sampled in each locality and only larvae located in those plants were collected. The emerged parasitoids from the larvae of *S. frugiperda* were identified and counted. The rate of parasitism and abundance of parasitoids were also examined. *Campoletis grioti* Blanchard (Hymenoptera: Ichneumonidae), *Chelonus insularis* Cresson (Hymenoptera: Braconidae), *Archytas marmoratus* Townsend (Diptera: Tachinidae) and *A. incertus* Macqart, *Ophion sp.* (Hymenoptera: Ichneumonidae), *Euplectrus platyhypenae* Howard (Hymenoptera: Eulophidae) and *Incamyia chilensis* Aldrich (Hymenoptera: Tachinidae) parasitoids were collected from the different stages of FAW. It was noted that the parasitoid *i.e. Campoletis grioti* was the most abundant and frequent during the period of survey. The rate of parasitism observed in Tucumán, Salta and Jujuy provinces were 21.96 percent, 17.87 percent and 6.63 percent respectively with an average of 18.93 percent.

Meagher *et al.* (2016) observed the larval stage of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), which were collected from the plants of sweet corn (*Zea mays* L.) in different fields. For the complete development the collected larvae were transferred to the laboratory condition. Total 8353 larvae of FAW were collected, of which 5062 larvae (60.6 %) developed into adult moth after feeding on corn tissue and artificial diet. Parasitoids were emerged from 2365 larvae (28.3%) and the parasitism rate varied from 1 to 91.7 percent, which depends on the site. The two most common parasitoids that emerged from larvae were the solitary endoparasitoids, *Cotesia marginiventris* Cresson and *Chelonus insularis* Cresson. Some other parasitoids of fall armyworm *viz. Aleiodes laphygmae* Viereck, *Meteorus spp.*, *Euplectrus platyhypenae* Howard, *Ophion flavidus* Brulle and unidentified species of Tachinidae were also observed.

Sisay (2018) observed three species of parasitoids namely, *Cotesia icipe* (Hymenoptera: Braconidae), *Palexorista zonata* (Diptera: Tachinidae) and *Charops ater* (Hymenoptera: Icheneumonidae), which were recovered from larvae of FAW. *Cotesia icipe* was the most common parasitoid that emerged from the larvae of FAW. The parasitism rate was ranged from 33.8 to 45.3 percent. On the other hand, parasitism by *Palexorista zonata* and *Charops ater* was comparatively low (6.4%).

Sisay *et al.* (2018) conducted a survey to determine the natural enemies of fall armyworm. A total of 287 smallholder maize fields were randomly selected and surveyed. Five different species of parasitoids were recovered from FAW eggs and larvae. *Cotesia icipe* (Hymenoptera: Braconidae) was the main parasitoid recorded with a percent parasitism rate of 37.6 percent. An egg-larval parasitoid *i.e.* C*helonus curvimaculatus* Cameron (Hymenoptera: Braconidae) was also recorded in with 4.8 percent parasitism rate. In 2018, six species of egg and larval parasitoids were recovered with *C. icipe* being the leading larval parasitoid, with parasitism percentage ranging from 16 to 42 percent in the three surveyed countries. In Kenya, *Telenomus remus* (Hymenoptera: Scelionidae) was the dominant egg parasitoid, causing up to 69.3 percent egg parasitism as compared to only 4 percent by *C. curvimaculatus*.

Shylesha *et al.* (2018) observed the associated natural enemies of *Spodoptera frugiperda* (J. E. Smith) (Insecta: Lepidoptera: Noctuidae). The survey discovered the natural parasitism of different stages of fall armyworm. Some important natural enemies; egg parasitoids *viz*., *Telenomus sp.* (Hymenoptera:Platygastridae) and *Trichogramma sp*. (Hymenoptea: Trichogrammatidae), gregarious larval parasitoids *i.e. Glyptapanteles creatonoti* Viereck (Hymenoptera: Braconidae), solitary larval parasitoid *i.e. Campoletis chloridae* Uchida (Hymenoptera: Ichneumonidae) and a solitary indeterminate larval-pupal parasitoid (Hymenoptera: Ichneumonidae: Ichneumoninae) were revealed from the survey. Fall armyworm was the first reported host for *Glyptapanteles creatonoti* across the globe.

Kenis *et al*. (2019) studied about the biological control of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), which provides an economically and environmentally safer choice to synthetic insecticides that are being used for the control of this pest. Different biological control strategies were considered, including the introduction of *Telenomus remus*, as an important egg parasitoid of fall armyworm. During survey, the parasitized egg masses of fall armyworm were collected and the emerged parasitoids were identified by molecular analysis and morphological observations.

2.3 Relative efficacy of different bio-rational insecticides against fall army worm on maize crop.

Kubo and Klocke (1981) worked on a biorational insecticides *i.e*. Azadirachtin. They observed the efficacy of Azadirachtin in disrupting both developmental and behavioural functions of several agricultural lepidopterous pests. The trial was conducted for determining the antifeedant activity against the fall armyworm, *Spodoptera frugiperda.* The most important result of this experiment was obtained by the addition of the antifeedent activity of Azadirachtin, which was proved to be useful by inhibition of ecdysis in test species.

Adamczyk *et al.* (1999) evaluated the efficacy of conventional and experimental insecticides against *Spodoptera frugiperda*. In experiment various insecticides including Emmamectin benzoate and Spinosad were tested and it was resulted that the insecticide, Spinosad was very effective against the 1st instar larvae of fall armyworm, while the activity against 5th instar was lower as compared to Emmamectin benzoate.

Patil (2000) worked on Neem seed kernal extract (NSKE) and evaluated that the minimum lepidopteran larval feeding was observed in irrespective of concentrations of NSKE. At 5 percent concentration of NSKE the leaf area consumed significantly less followed by NSKE (20%).

Barapatre (2001) evaluated that, among the different indigenous technology the mixture of Pongamia + aloe + NSKE + cow urine is useful to manage the lepidopteran pests, because of its highest antifeedant activity. By the investigation he observed that, this mixture is responsible for 75.75 percent larval weight reduction over control followed by mixture of agave + chilli (71.13 %) and neem seed kernel extract (65.44).

Capalbo *et al.* (2001) observed the effect of *Bacillus thuringiensis* tolworthi against the fall armyworm. *Bacillus thuringiensis* tolworthi @ 300 L/ha was sprayed in maize field to evaluate the efficacy of this biopesticide and resulted that, after 24 hrs of first application, eggs had hatched and initial instar larvae were feeding on the leaves of the plants. After 48 hrs of application only dead, black larvae were found. After twenty days of 1^{st} application of *Bacillus thuringiensis* the same level of initial larvae infestation was recorded.

Zamora *et al.* (2008) evaluated the effect of spinosad, methoxyfenozide, and azadirachtin on eggs and larvae of fall armyworm, *Spodoptera frugiperda* (J.E. Smith). Ovicidal activity was measured on egg masses of < 48 h old laid on brown paper, in different concentrations of each insecticide, which were diluted in 0.01 percent of sodium dodecyl sulphate. Only spinosad and azadirachtin showed ovicidal activity in concentrations up to 1000 mg/L, which caused mortalities between 12 and 31 percent. Mortality of larvae that emerged from the treated eggs was increased only with spinosad and methoxyfenozide. In contrast, the weight of 6^{th} instar larvae from treated eggs was not affected by the insecticides, except by spinosad at 3.16 mg a.i. /L, in that situation the weight of larvae (275.5 mg) increased as compared to the control (183.6 mg).

Laxmanrao (2009) reported that 1500 ppm of Azarirachtin showed least percent of mortality *i.e.*, 29.52 percent on first spray and 26.93 percent after second spray on lepidopteran larvae.

Hardke *et al.* (2011) worked on the dose- mortality response of *Spodoptera frugiperda* larvae to confirm field efficiency of insecticides against the natural infestations. They worked on some selected insecticides *viz.* Spinetoram, Chlorantraniliprole, Spinosad, Novaluron. The field trial against the larvae of *S. frugiperda* resulted that Chlorantraniliprole minimizes the number of infested whorls below that in the other insecticides as well as control plot. They also resulted that Chlorantraniliprole was responsible for about 93.8 percent, 85.9 percent, 82.8 percent and 53.1 percent of mortality at 7th, 14th, 21th and 28th DAT, respectively.

Zarate *et al.* (2011) evaluated the lethal and sublethal effects of the ecdysone agonist Methoxyfenozide on the fall armyworm, *Spodoptera frugiperda* (J. E. Smith). The experiment was performed by feeding a diet treated with Methoxyfenozide to 5th instar larvae until the pupation. On the 7th day of experiment, the larval mortality increased to 8 percent and 26 percent in the low and high concentration groups, respectively. Prior to pupation, a progressive larval mortality of 12 percent for LC10 and 60 percent for LC25 was observed. The treated larvae had lower pupal weight, higher pupal mortality, appearance of more deformed pupae and deformed moths than untreated larvae. By the experiment, it was noted that if 5th instar larvae of *S. frugiperda* were treated with Methoxyfenozide, the adults were neither affected in their average cumulative number of egg laid by per female (fecundity) nor egg hatching percentage (fertility) or the sex ratio. They also resulted that the mixture of sub- lethal and lethal effect of methoxyfenozide may have significant consequences population dynamics of *S. frugiperda*.

Belay *et al.* (2012) worked on the susceptibility of *Spodoptera frugiperda* against various bio- rational insecticides viz. Spinetoram (11.7%), Spinosad (44.2%), Cholantraniliprole (18.4%) and resulted that after 16 hrs of application of insecticides, Spinetoram caused significantly higher (>60%) FAW mortality as compared to others, while the effect of Chlorantraniliprole and Spinosad was intermediate. After 48 hrs of application of insecticides Spinosad caused a level of mortality that was similar to that Spinetoram. At 96 hrs after application, all the insecticides resulted in more than 80 percent of FAW larval mortality.

Metzler and Mora (2017) evaluated the effect of Spinetoram, Solaris 6SC® (75ml/ha) for managing the population of *Spodoptera frugiperda* on corn crop and resulted that the areas treated with Solaris 6SC® had the less quantity of corn damaged by this pest.

Bateman *et al.* (2018) worked on biopesticides such as microbials and microbial extracts, macrobials and semiochemicals are generally considered to be lower risk options for pest management and they are a promising avenue for exploration. When used in conjunction with good crop management, they can help to keep pest levels under control, reducing the need to apply other pesticides. This study provides a basis for designing interventions to make biopesticides more widely available for fall armyworm control in Africa. The report identifies biopesticide active ingredients (AI) which are registered for use against fall armyworm and provides an assessment of how appropriate these will be for use by smallholder farmers in Africa.

Sharma *et al.* (2018) conducted a field experiments in winter maize with the aim of evaluating the potential of bio-rational pesticides to manage the armyworm. Treatments were: *Metarrhizium anisopliae* (0.2ml/lit water), Nuclear Polyhedrosis Virus (NPV) (2.5gm/lit water), Spinosad 45% SC (0.25ml/liter of water)**,** Multineem (*Azadriachta indica*) (2 .0 ml/ liter water), Furadan 3G (3-4g/ Whorl application) and control. The experiments were completely randomized block design with three replications. Spinosad treated plots demonstrated the lowest damage (0.884%) , which was considerably lower ($P< 0.05$) than other treatments.

Seth *et al.* (2018) found that the control of lepidopteran pests, the use of eco-friendly bio-rational control measures, sterile insect technique (SIT) and Inherited Sterility (IS) technique were useful against these pests. Sterile insect technique (SIT IS) may be suitable with other bio-rational approach to control.

Viteri *et al.* (2020) evaluated the efficacy of bio-ration insecticides *viz*. Spinetoram, Chlorantraniliprole and *Bacillus thuringiensis* against fall armyworm on two different cultivar *viz*. Juana Diaz and Lajas of sweet corn and reported that Spinetoram 11.7% SC @ 1.5ml/l caused 78.6 percent larval mortality in cultivar Juana Diaz, while 54.3 percent in cultivar Lajas. Chlorantraniliprole 18.4% @ 0.6ml/l caused 67.8 and 37.0 percent larval mortality in cultivar Juana Diaz and Lajas, respectively. In case of *Bacillus thuringiensis* 23.7% @ 4.8 g/l, this data recorded 27.5 and 30.0 percent, respectively.

CHAPTER-III
MATERIALS AND METHODS

The present study entitled "Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera:Noctuidae) along with its biorational management on kharif maize crop" was conducted during 2019-20.

3.1 Location and site

The laboratory studies related to biology and behaviour was carried out at Biocontrol laboratory, Department of Entomology, while field experiments were conducted at Research cum Instructional Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, during 2019-20. College of Agriculture, IGKV situated at Raipur. Raipur comes under the tropical region of India and situated in central part of Chhattisgarh plains.

3.1.1 Geographical situation

Raipur, the place of investigation is situated in mid eastern part of Chhattisgarh at latitude of 21°16'N, longitude of 81°36'E and at 289.56 of meters altitude above from the mean sea level.

3.1.2 Climatic condition

The climatic condition of Raipur region is generally sub-humid to semi-arid, which is comes under seventh agro-climatic zone of the country. The mean annual precipitation of this region is about 1200-1400mm (based on 80 years mean) and about 85 per cent of precipitation is received between mid June to mid September months and very little by occasional showers in winter and summer months. The maximum temperature raises up to 46˚C during the days of summer and minimum temperature drop down as low as about 6˚C during winter season. The average maximum and minimum temperature recorded about 42.9˚C and 10.1˚C in month of May and December. The relative humidity of the months June to October is high and the wind velocity is high from May to August with its peak in June-July months.

3.1.3 Weather condition during crop period

The test crop received 954.3 mm rainfall during its entire growth and maturity period. The maximum temperature 36.5°C received during the crop period in third week of July and the minimum temperature was recorded 22.0°C in the fourth week of October. The average maximum temperature of different months varied from 25.0°C to 36.5.0°C, where as monthly average minimum temperature varied between 22.0°C to 27.0°C. Relative humidity throughout the crop period varied from 61.0 to 95.0 per cent and monthly average maximum relative humidity varied between 83.0 to 95.0 per cent and minimum relative humidity varied between 61 to 95 percent. Weekly average meteorological data as recorded by Meteorological Observatory, IGKV, Raipur, during the experimental study, is presented in (**Appendix-I**)

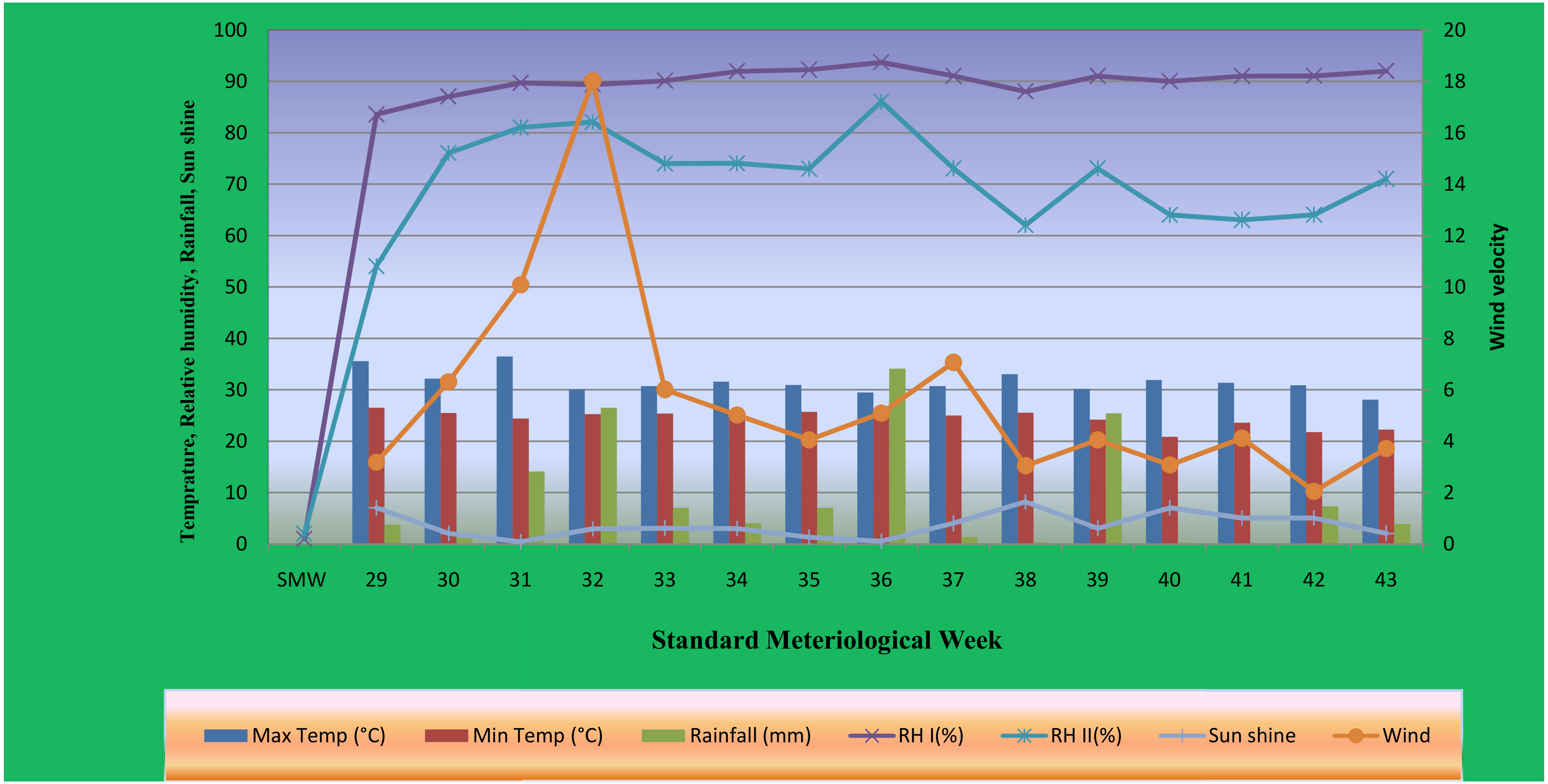


Fig:-3.1 Meteorological data during crop growth period (Kharif season2019-20)

The details about, material used and techniques applied during the course of investigation are described objective wise briefly as under –

3.4. *In vitro* studies on the biology and behaviour of fall armyworm on maize crop.

A study on biology and behaviour of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) conducted in the Biocontrol laboratory of Department of Entomology, Indira Gandhi Krishi Vishwavidyalaya Raipur, Chhattisgarh during the period of July to November, 2019 under controlled laboratory conditions (25 ± 2 °C, 70 ± 10 % RH).

3.4.1 Nucleus culture of *Spodoptera frugiperda*

To maintain the culture of *Spodoptera frugiperda* (J.E. Smith), the larval stage was collected from the maize plants from the experimental field, brought into the Biocontrol laboratory and was allowed to grow until they become adult. After adult emergence the male and female moth were separated and placed for mating in transparent jars, covered with a fine muslin cloth and was secured with rubber band. The inner surface of transparent jars was lined with a black paper sheet, which provided clear visibility of eggs on the surface. 10 per cent honey solution on a cotton swab was placed in each jar for moth feeding. Eggs of fall armyworm laid on the bottom of glass jars were collected for further multiplication and use. These eggs were used as nucleus culture for mass rearing of *S. frugiperda.*

3.4.2 Study of biology of *S. frugiperda* on different genotypes of maize crop-

The present study on biology of *S. frugiperda* was conducted by using a completely randomized block design with three treatments and twenty replications. Each replication was performed by using individual larvae (*i.e.*20 larvae per treatment = total of 60 larvae).

For the experiment, newly emerged larvae (neonate) were kept in petri dishes individually and fed on newly emerged leaves of three different genotypes of maize crop *i.e.* hybrid maize (PRO-4212), fodder maize (African tall) and sweet corn (Sugar-75) which were collected from the experimental field. The larvae were reared until they become adult. After adult emergence the male and female moth were separated and placed for mating in transparent jars, covered with a fine muslin cloth and was secured with rubber band. The inner surface of transparent jars were lined with a black paper sheet, which helps to provided clear visibility of eggs on the surface of jars, where the adults of fall armyworm were observed regularly for their egg laying (oviposition). After mating of male and female of FAW adults, the female moths laid eggs. In this way the egg masses were collected from each treatment separately. Data were carefully observed for pre-oviposition, oviposition, post-oviposition, fecundity rate, Shape, size and colour of eggs for each treatment. For the measurement of size of eggs, ocular micrometer was used after calibration.

The eggs were allowed to hatch, then the neonates were carefully collected by the help of a soft camel hair brush and were individually transferred in twenty petri dishes for each treatment (In each petri dish, newly emerged leaves of maize genotype i.e. Hybrid corn, sweet corn, fodder corn were supplied separately in every morning to each larva as food and the leaves of each genotype of maize were renewed at 12 hours interval and wet cotton was used to keep the leaves turgid and fresh). Observations regarding the larval stage i.e. larval period, number of instars, colour and pattern of each instar were recorded carefully. Length of each instar was recorded with the help of meter scale.

The larvae were fed till all they pupate. The pupae thus collected from each jar. In pre-pupal and pupal period; duration, colour and type of pupa were recorded. After the adult emergence; male and female adult longevity, colour of moth, pattern on wings, male and female differentiation, and sex ratio parameters were recorded.

The petri dishes used in the experiment were thoroughly washed in detergent, treated with 2% formalin and then dried to check microbial contamination in the insect culture.

3.4.3 Study of behaviour of *S. frugiperda* on maize crop

For the study of different behaviours of fall armyworm, required stages were collected from the reared stock. Following behavioural studies of fall armyworm were conducted-

3.4.3.1 Ovipositional preference behaviour

For the study of ovipositional preference behaviour, maize plants (‘PRO-4212’ cultivar) were grown in plastic pots that contained soil. The trial was conducted, when plants attained of 5-leaf stage. Each pot was equidistantly covered with a metal pipe cage frame and a fine mesh screen was placed over the frame. After that, a pair of male and female moth was release into each cage. 10 per cent honey solution on a cotton swab was placed inside each cage for moth feeding. The adults were allowed to mate and after 2 to 3 days of oviposition period, egg position inside the plant (bottom, middle, and upper canopy) were evaluated. Each plant was examined and preferred places for oviposition were observed. The treatment was replicated ten times.

3.4.3.2 Neonate feeding preference behaviour

For the study of feeding preference behaviour of fall armyworm, egg masses were obtained from the research colony as previously described. The study was conducted by using a completely randomized design with three treatments and ten replications on each genotype of corn. Three corn genotypes *i.e.* hybrid corn ('PRO-4212' cultivar), fodder corn ('African tall' cultivar) and sweet corn ('Sugar75' cultivar) were indicating three different treatments. After hatching, neonates (<24 h age) were randomly selected and transferred into petri dishes, by using a fine paintbrush. The petri dishes were covered with suitable caps to avoid the migration of larvae**.** Each petri dish contained one neonate and 5 g of leaves of corn as feed. Corn leaves were replaced every day and wet cotton balls were used to maintain the turbidity of leaves. Larval survival was evaluated daily until next instar, by recording the weight of leaf consumed by the larva in 24 hrs and number of live larvae. Larval development was also evaluated.

3.4.3.3 Larval dispersal behaviour

Maize plants ('PRO-4212' cultivar) were grown in plastic pots are used for study of larval dispersal behaviour up to 3rd instar on plant. When the plant attained 5-leaf stage, each pot was equidistantly covered with a metal pipe cage frame and a fine mesh screen was used to cover the frame. A mass of 50 eggs were clipped in each plant of maize inside the cage. The number of egg was counted by using stereo microscope. The entire cohort was continuously observed for 1 hour after the first larva emerged from the egg mass. Remaining observations were carried out according to larval instars that which instar preferred which part of plant (up to 3rd instar). Larval movement on the corn plant was evaluated based upon the number of recorded larvae in each plant zone. The treatment was replicated five times.

3.4.3.4 Cannibalism behaviour

The experiment was conducted with three different treatments. In first treatment, a sixth instar larva of 13 days was housed individually in petri dish with enough food (maize leaves, 'PRO-4212' cultivar) for 48 hrs. Two larvae of fourth and fifth instar were provided to serve as a potential cannibalistic victim.

In second treatment, a sixth instar larva of 13 days was housed individually in petri dish with enough food (maize leaves, 'PRO-4212' cultivar) for 48 hrs and two larvae of fifth instar of 11 days were provided to serve as a potential cannibalistic victim.

In third treatment, a sixth instar larva of 13 days was housed individually in petri dish with enough food (maize leaves, 'PRO-4212' cultivar) for 48 hrs, after that a larva of same age was provided to serve as a potential cannibalistic victim.

The number of larvae cannibalized was recorded after 48 h, when the food became limited. Ten replicates of each treatment were set up. Missing larvae (assumed to be cannibalized) were recorded in interval of 48 hrs. Direct observations verified the occurrence of cannibalism.

3.4.3.5 Mating behaviour

When the maize plant ('PRO-4212' cultivar), attained 5-leaf stage, each pot was equidistantly covered with a metal pipe cage frame and a fine mesh screen was placed over the frame, after that one pair of virgin, recently emerged (<24 h) male and female moths of *S. frugiperda* were release into each cage. 10 per cent honey solution on a cotton swab was placed inside each cage for moth feeding. Moths were maintained in their cages. Observation on mating viz. time and duration of mating were carried out in every one hour from 6:00 pm to 5:00am of the following day.

Fig. 3.2: View of biology and behavioural study of *Spodoptera frugiperda*.

3.5. Studies on parasitoids of different stages of fall armyworm in laboratory conditions.

During the period of incidence of fall armyworm, different stages *i.e.* egg, larva and pupa were collected from the maize plant of different experimental fields. They placed in transparent jars for further rearing, which was covered with a fine muslin cloth and secured with rubber band. The whole treatment was kept in proper observation and the noticed unidentified parasitoids of any stage were sending for identification.

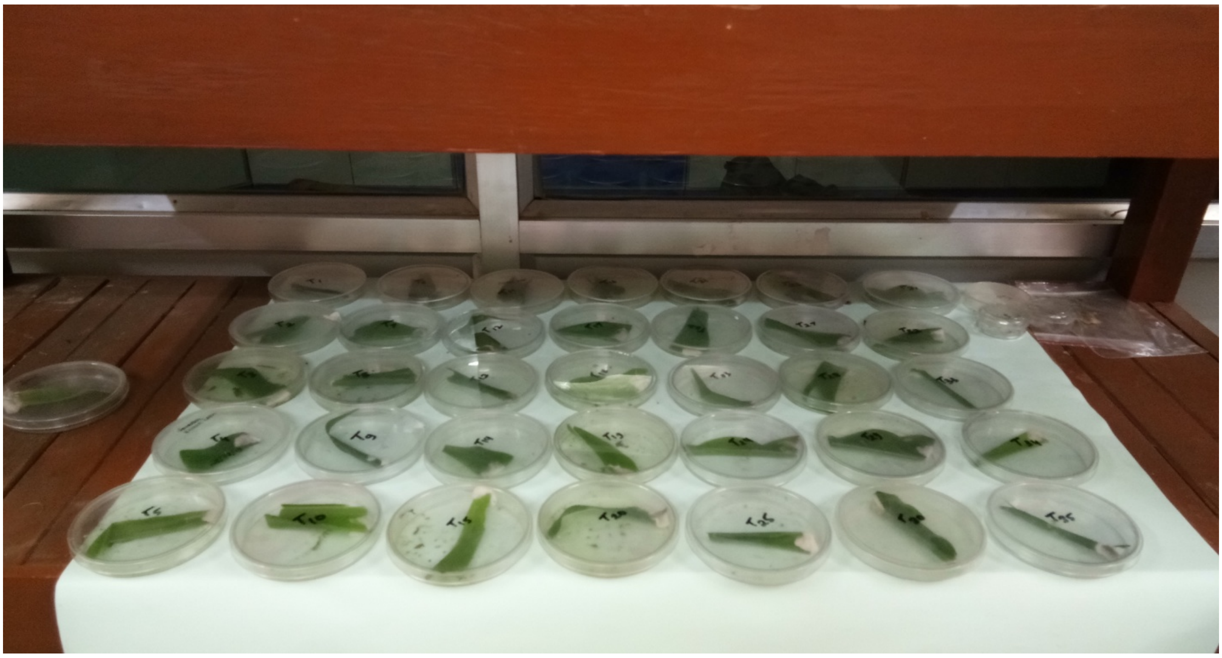


Fig. 3.3: Study of parasitoids of *Spodoptera frugiperda*.

3.6. Relative efficacy of different bio-rational insecticides against fall armyworm on maize crop.

The present study related to biorational management of fall armyworm on kharif maize crop was conducted during 2019-20, for the purpose to evaluate the relative efficacy of eight bio-rational insecticides against *Spodoptera frugiperda* infesting maize crop. The field experiment was conducted at Research Cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.).

3.6.1 Experimental details:

Season	: Kharif 2019-20
Name of variety	: PRO-4212
Design	: Randomized Block Design (RBD)
Replication	: 03
Treatment	: 09
Plant spacing	: 75 cm×20 cm
Date of sowing	: 19/07/2019
Plot size	: 5 m x 4 m
Distance between replications	: 1m
Distance between plots	: 0.5m

3.6.2 Applications of Bio-rational Insecticides

Eight bio-rational insecticides were evaluated for the management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith). The foliar spray of insecticides was applied with the help of knapsack sprayer of 15 liter capacity. Spray fluid was prepared by mixing of measured quantity of insecticides in calculated quantity of water to get the required concentrations to be used in experiment. Before pouring in to the sprayer, the spray fluid was stirred thoroughly. Washing of sprayer was done before the application of another insecticide, by flushing sufficient clean water. All the necessary care was taken to prevent the drift of insecticides to the adjacent plots. Spraying of insecticides was done in morning hours. Insecticides were sprayed thrice, on 15, 30 and 45 days after the emergence of crop. The details about the test insecticides are shown in Table 3.1.

Table 3.1: Bio-rational insecticides used for management of *Spodoptera frugiperda* on maize.

Treatment	Technical name	Formulation	Concentration (%)	Quantity required (ml or g/ l)
T1	Spinetoram	11.7% SC	0.014	0.3
T2	Chlorantraniliprole	18.5% SC	0.07	3
T3	Emamectin benzoate	5% SG	0.0025	0.5
T4	Pyriproxifen	10% EC	0.01	1
T5	*Beaveria bassiana*	2×10^6 cfu/g WP	0.4	4
T6	Azadirachtin	0.15 EC	0.0006	4
T7	Buprofezin	25SC	0.04	1.6
T8	*Bacillus thuringiensis*	2×10^6 spores/mg WP	0.15	1.5
T9	Untreated	-	-	-

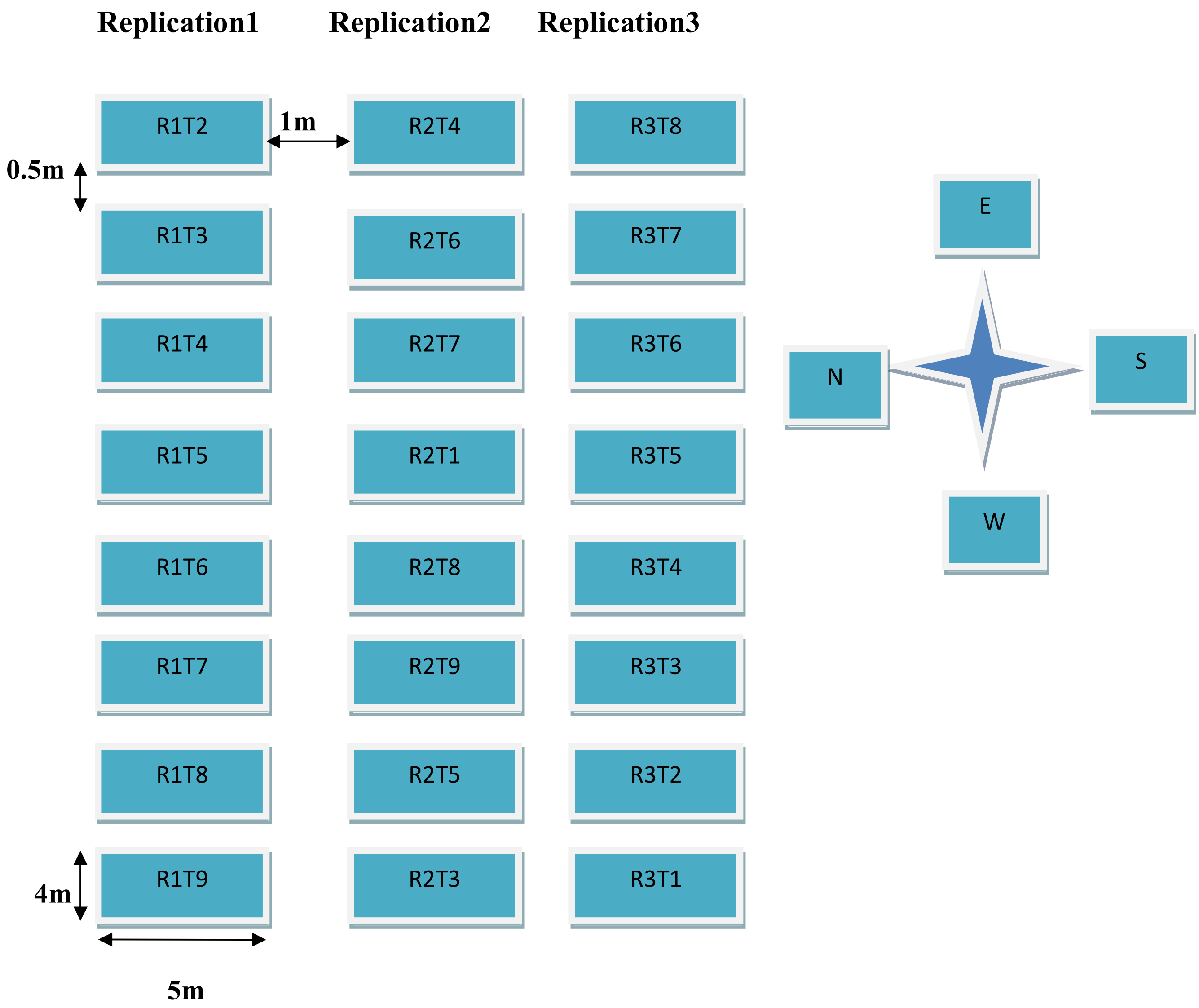


Fig. 3.4: Layout plan for experiment-3.

Fig. 3.5: View of the bio-rational management trial.

3.6.3 Method of taking observations

The pre-treatment observations were made 24 hours before spraying , while the post-treatment observations were taken 1, 3 and 7 days after spraying on five plants randomly selected from each plot. Following observations were observed in the experimental plots-

1. Number of larvae / plant.
2. Per cent reduction
3. Yield /plot

The percent reduction of *S. frugiperda* was subjected to square root transformation. These transformed values were analyzed statistically by using the techniques of analysis of variance for randomized block design and significance was tested by “F” test.

The mean original data of percentage reduction was calculated reduction over with the following formula (*Abbott's* 1925)

$$\text{Percent reduction} = \frac{C-T}{C} \times 100$$

Where, T = Insect population reduction in treated plot

C = Insect population reduction in control plot

3.6.3.1 Yield and Economics

The yield data of each treatment was recorded according to replication and subjected to statistical analysis to test the significance of mean yield in different treatments. Per cent increase in yield over untreated control was also evaluated by following formula (Gomez & Gomez, 1984).

$$\text{Percent increase in yield over control} = \frac{T-C}{C} \text{ x } 100$$

Where, T = Yield from treated plot.

C = Yield from control plot.

Economics of various insecticides were developed according to the market price of the goods and wages that prevailed during studies. The factors considered were cost of various insecticides and additional costs involved for economic analysis. About the ratio of gross and net returns and profit costs also worked out. The increased yield value over untreated control was calculated by multiplying the increased yield over control through prevailing maize market price (Rs. Per quintal). The net profit on untreated control was worked out by deducting insecticides costs and labor charges from the price of increased control yield. The benefit: cost ratio was also calculated by dividing net profit by the total cost (Insecticides and labor charges) of regulation.

$$\text{Benefit cost ratio} = \frac{\text{Net returns}}{\text{Total cost (Insecticides + labour charges)}}$$

CHAPTER IV
RESULT AND DISCUSSION

The present study entitled "Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera:Noctuidae) along with its biorational management on kharif maize crop" was conducted during 2019-20 in kharif season. The experiments related to biology and behaviour of fall armyworm was conducted at Biocontrol laboratory IGKV, Raipur (C.G.) and the field experiment was conducted at Research Cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.). The findings of investigations conducted on the following objectives-

1. *In vitro* studies on the biology and behaviour of fall armyworm on maize crop.
2. Studies on parasitoids of different stages of fall armyworm in laboratory conditions.
3. Relative efficacy of different bio-rational insecticides against fall army worm on maize crop.

4.1 *In vitro* studies on the biology and behaviour of fall armyworm on maize crop.

4.1.1 Biology of fall armyworm on different genotypes of maize crop

Detailed biology of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) was studied on different kharif maize genotypes i.e. fodder corn, sweet corn and hybrid corn crop under the laboratory conditions, from August to November 2019.

4.1.1.1 Egg

Adult female of *S. frugiperda* deposited the eggs in a cluster/mass and ranged from 387 to 579. The eggs were sometimes deposited in two to three tiers, but mostly eggs were spread over a single layer. A gravid female laid six to seven egg masses and sparsely covered from the abdominal tip with cottony white scales (Fig. 4.1). All the above observations were similar for each genotype of maize crop, which was used in experiment as a host.

Similarly, it was reported that female moth laid eggs in clusters ranged from 55 to 888 (Sharanabasappa *et al.*, 2018). Igyuve *et al.* (2018) reported that the number of eggs per mass varies considerably but is often 100 to 200. The egg masses containing about 150 to 200 eggs, which were arranged in two to four layers (CABI, 2019).

4.1.1.1.1 Ovipositional site

Adult females were deposited their eggs on upper or lower surface of leaves (lower surface was mostly preferred) and also in whorls, in a mass. Favored sites for oviposition were almost similar in each genotype of maize. They mostly preferred lower surface of leaf for oviposition, it might lower the chances of predation/ parasitism by natural enemies. Similar egg laying pattern was observed by Sharanabasappa *et al.* (2018), Igyuve *et al.* (2018).

4.1.1.1.2 Colour and shape

The eggs were flattened dorso- ventrally in shape; initially pale green for one day turned to golden yellowish and eventually turned to black in colour before hatching. The females were also deposited a layer of whitish scales, which covered the egg mass and gave a moldy or furry appearance in all the three genotypes *viz.* fodder corn, sweet corn and hybrid corn (Fig.4.1).

Sharanabasappa *et al.* (2018) observed that the eggs were dorso-ventrally flattened; initially these were pale green for one day turned to golden yellowish and ultimately turned to black before hatching. Igyuve *et al.* (2018) reported that the eggs were dome in shape; the base was flattened and the egg curved upward to a broadly rounded point at the apex. Similarly the egg was observed 'dome' in shape according to Prasanna *et al*. (2018).

4.1.1.1.3 Size

The eggs were 0.39 to 0.53 mm in length with an average of 0.45 ± 0.01 mm and 0.41 to 0.46 mm in width with an average of 0.43 ± 0.01 mm when the insect was reared in fodder corn. The eggs were 0.38 to 0.60 mm in length with an average of 0.48 ± 0.08 mm and 0.38 to 0.46 mm wide with an average of 0.41 ± 0.02 mm, when the insect was grown in sweet corn. In hybrid corn, the length of eggs was 0.39 to 0.59 mm with an average of 0.46 ± 0.07 mm and the width was ranged from 0.38 to 0.46 mm with an average of 0.42 ± 0.02 mm. (Table 4.1)

Similar observations were taken by Prasanna *et al.* (2018), where the diameter and height of egg were measured as 0.4 mm and 0.3 mm, respectively.

Table 4.1: Size of eggs of *S. frugiperda* on different genotypes of maize crop.

S. N.	Genotype	No of eggs measured	Size (mm)					
			Length			Breadth		
			Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(African tall)	10	0.3	0.5	0.40±0.01	0.3	0.4	0.34±0.01
2.	Sweet corn(Sugar 75)	10	0.3	0.5	0.48±0.02	0.3	0.4	0.39±0.01
3.	Hybrid corn(PRO-4212)	10	0.3	0.4	0.39±0.01	0.3	0.4	0.31±0.01
	SE (m)±				0.016			0.012
	CD (5%)				0.045			0.036

4.1.1.1.4 Incubation period

The incubation period was 1 to 2 days with an average of 1.90±0.10 days, 2 days with an average of 2.00±0.00 days, 2 to 3 days with an average of 2.90±0.10 days, where the selected host was fodder corn, sweet corn and hybrid corn from August to November respectively (Table 4.2).

The incubation period of *S. frugiperda* was observed with an average of 2.63 ± 0.03 days on corn crop (Murua *et al.,* 2008). More or less similar incubation period were noted by Sharanabasappa *et al.* (2018), in maize crop ranged from 2 to 3 with an average of 2.50 ± 0.50 days. According to Pitre and Hogg (1983) the duration of the egg stage is only two to three days during the summer months.

Table 4.2: Incubation period of egg of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	No. of eggs examined	Incubation period (Days)		
			Min	Max	Mean ± SD
1.	Fodder corn(African tall)	10	1	2	1.90±0.10
2.	Sweet corn(Sugar 75)	10	2	2	2.00±0.00
3.	Hybrid corn(PRO-4212)	10	2	3	2.90±0.10
	SE (m) ±				0.082
	CD (5%)				0.238

4.1.1.2 Larva

It was observed that during the larval period of *S. frugiperda*, the caterpillar molted for five times thus passed through six larval instars in each genotype *i.e*. fodder corn, sweet corn and hybrid corn. Similar molting pattern and number of instars were observed by Igyuve *et al.* (2018) and Sharanabasappa *et al.* (2018) on maize crop. The characteristics and duration of each larval instar were observed and recorded carefully. The body size (including length and breadth of body) and head capsule width of each instar were also measured and recorded.

4.1.1.2.1 First instar

The soft bodied neonate larva hatched out from the egg by making a hole on the surface of egg shell. Neonate larvae were very tiny, with comparatively a large black head. The body of larvae was pale green to yellowish in colour, which was covered with small hairs (Fig.4.1). All the observations were almost similar in each genotype. More or less similar observations were taken by Sharanabasappa *et al.* (2018) on maize crop. The length, head capsule width and duration of 1st instar larval stage were recorded.

The length of first instar larva was varied from 0.8 to 1.3 mm with an average of 1.20 ± 0.02 mm, for fodder corn. For the sweet corn the length of first instar larva was varied from 1.0 to 1.9 mm with an average of 1.31 ± 0.04 mm. For the hybrid corn the length of first instar larva was varied from 1.0 to 1.9 mm with an average of 1.37 ± 0.05 mm (Table 4.3). First instar larvae attains length of 1.7 mm on maize crop (Igyuve *et al.*, 2018).

The duration of first instar larvae was noted 2 days in all the replications with an average of 2.00 ± 0.00 days for fodder corn. Similarly in case of sweet corn this duration was noted 2 days in all 20 replications with an average of 2.00 ± 0.00 days but in case of hybrid corn, this duration is varied from 2 to 3 days with an average of 2.10 ± 0.06 days (Table 4.4). According to Igyuve *et al.* (2018) the mean duration of first instar larvae was 3.3 days on maize crop. Sharanabasappa *et al.* (2018) noted the duration of first instar larvae as 2 to 3 days with an average of 2.60 ± 0.49 days on maize crop.

The width of head capsule of first instar larvae varied from 0.31 to 0.36 mm with an average of 0.34 ± 0.003 mm, 0.34 to 0.38 mm with an average of 0.36 ± 0.003 mm, 0.34 to 0.38 mm with an average of 0.36 ± 0.003 mm, when insect was reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.5) (Fig.4.2). The head capsule width of first instar was measured 0.32 to 0.35 mm with an average of o.34 ± 0.01 mm by Sharanabasappa *et al*. (2018). Igyuve *et al.* (2018) noted the head capsule width as 0.35 mm of first instar of *S. frugiperda*.

4.1.1.2.2 Second instar

The larvae were observed darken and appear greenish brown in colour, after the completion of the first molting. They were also increased in length as well as in breadth in all the genotypes (Fig.4.1). Similar body colour of second instar of *S. frugiperda* was recorded by Sharanabasappa *et al.* (2018) on maize crop.

The length of second instar larvae was varied from 2.1 to 3.7 mm with an average of 2.56 ± 0.10 mm for fodder corn. For the sweet corn the length of second instar larvae was varied from 2.7 to 3.2 mm with an average of 3.08 ± 0.02 mm respectively. For the hybrid corn the length of second instar larvae was varied from 2.0 to 3.9 mm with an average of 3.11 ± 0.07 mm (Table 4.3). Second instar larvae attain length of 3.5 mm on maize crop (Igyuve *et al.*, 2018).

The duration of second instar larvae was varied from 2 to 4 days with an average of 2.95 ± 0.08 days for fodder corn. In case of sweet corn this duration was varied from 2 to 4 days with an average of 3.00 ± 0.07 days similarly in case of hybrid corn, this duration was varied from 2 to 4 days with an average of 3.90 ± 0.10 days (Table 4.4). According to Igyuve *et al.* (2018) the mean duration of second instar larvae was 1.7 days on maize crop. Sharanabasappa *et al.* (2018) noted the duration of second instar larvae as 2 to 3 days with an average of 2.60 ± 0.49 days on maize crop.

The width of head capsule of second instar larvae was varied from 0.41 to 0.46 mm with an average of 0.43 ± 0.003 mm, 0.44 to 0.48 mm with an average of 0.46 ± 0.003 mm, 0.44 to 0.48 mm with an average of 0.46 ± 0.003 mm, when insect was reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.5) (Fig.4.2). The head capsule width of second instar was measured 0.47 to 0.52 mm with an average of 0.48 ± 0.01 mm by Sharanabasappa *et al*. (2018). Igyuve *et al.* (2018) noted the head capsule width as 0.45 mm of second instar of *S. frugiperda*.

4.1.1.2.3 Third instar

Third instar larvae were noted similar in colour to previous instar in all the genotypes *viz.* fodder corn, sweet corn and hybrid corn but typically darken just prior to molting to the proceeding instar (Fig.4.1) same as reported by Sharanabasappa *et al.* (2018) on maize crop.

The length of third instar larvae was varied from 5.5 to 6.3 mm with an average of 5.86 ± 0.04 mm for fodder corn. For the sweet corn the length of third instar larvae was varied from 5.8 to 6.9 mm with an average of 6.21 ± 0.07 mm. For the hybrid corn the length of third instar larvae was varied from 5.1 to 6.8 mm with an average of 5.92 ± 0.14 mm (Table 4.3). Third instar larvae attain length of 6.4 mm on maize crop (Igyuve *et al.*, 2018).

The duration of third instar larvae was varied from 2 to 3 days with an average of 2.05 ± 0.05 days for fodder corn. In case of sweet corn this duration was varied from 2 to 3 days with an average of 2.10 ± 0.06 days similarly in case of hybrid corn, this duration was varied from 2 to 3 days with an average of 2.95 ± 0.05 days (Table 4.4). According to Igyuve *et al.* (2018) the mean duration of third instar larvae was 1.5 days on maize crop. Sharanabasappa *et al.* (2018) noted the duration of third instar larvae as 2 days with an average of 2.00 ± 0.00 days on maize crop.

The width of head capsule of third instar larvae was varied from 0.71 to 0.76 mm with an average of 0.74 ± 0.003 mm, 0.74 to 0.78 mm with an average of 0.76 ± 0.003 mm, 0.74 to 0.78 mm with an average of 0.76 ± 0.003 mm, when insect was reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.5) (Fig.4.2). The head capsule width of third instar was measured 0.80 to 0.85 mm with an average of 0.81 ± 0.02 mm by Sharanabasappa *et al.* (2018). Igyuve *et al.* (2018) noted the head capsule width as 0.75 mm of third instar of *S. frugiperda*.

4.1.1.2.4 Fourth instar

Fourth instar larvae were observed brown to black in colour. The larvae exhibit a prominent inverted "Y" on head capsule in all the genotypes *viz.* fodder corn, sweet corn and hybrid corn (Fig.4.1). The head capsule was dark brownish to black in colour similarly as observed by Sharanabasappa *et al.* (2018) on maize crop.

The length of fourth instar larvae was varied from 9.2 to 10.3 mm with an average of 9.74 ± 0.08 mm for fodder corn. For the sweet corn the length of fourth instar larvae was varied from 9.7 to 10.8 mm with an average of 10.08 ± 0.06 mm. For the hybrid corn the length of fourth instar larvae was varied from 9.1 to 10.7 mm with an average of 9.97 ± 0.12 mm (Table 4.3). Fourth instar larvae attain length of 10.0 mm on maize crop (Igyuve *et al.*, 2018).

The duration of fourth instar larvae was varied from 2 to 3 days with an average of 2.15 ± 0.08 days for fodder corn. In case of sweet corn this duration was varied from 2 to 3 days with an average of 2.10 ± 0.06 days similarly in case of hybrid corn, this duration was varied from 2 to 3 days with an average of 3.00 ± 0.00 days (Table 4.4). According to Igyuve *et al.* (2018) the mean duration of fourth instar larvae was 1.5 days on maize crop. Sharanabasappa *et al.* (2018) noted the duration of fourth instar larvae as 2 days with an average of 2.00 ± 0.00 days on maize crop.

The width of head capsule of fourth instar larvae was varied from 1.26 to 1.31 mm with an average of 1.29 ± 0.003 mm, 1.29 to 1.33 mm with an average of 1.31 ± 0.003 mm, 1.29 to 1.33 mm with an average of 1.31 ± 0.003 mm, when insect was reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.5) (Fig.4.2). The head capsule width of fourth instar was measured 1.17 to 1.30 mm with an average of 1.22 ± 0.05 mm by Sharanabasappa *et al*. (2018). Igyuve *et al.* (2018) noted the head capsule width as 1.3 mm of fourth instar of *S. frugiperda*.

4.1.1.2.5 Fifth instar

Fifth instar larvae were observed similar to their older instar but increased in size in all the genotypes *viz.* fodder corn, sweet corn and hybrid corn. Non continuous white line was noted in the mid- dorsal area of the body, as well as yellowish flecking were present on the ventral surface of abdomen. Larvae also have a distinct pattern of four "dots" on the eighth abdominal segment (Fig.4.1). More or less similar observations were taken by Sharanabasappa *et al.* (2018) on maize crop.

The length of fifth instar larvae was varied from 15.4 to 16.5 mm with an average of 16.07 ± 0.06 mm for fodder corn. For the sweet corn the length of fifth instar larvae was varied from 15.0 to 16.8 mm with an average of 16.42 ± 0.12 mm. For the hybrid corn the length of fifth instar larvae was varied from 15.3 to 17.2 mm with an average of 16.01 ± 0.14 mm (Table 4.3). Fifth instar larvae attain length of 17.2 mm on maize crop (Igyuve *et al.*, 2018).

The duration of fifth instar larvae was varied from 3 to 4 days with an average of 3.10 ± 0.06 days for fodder corn. In case of sweet corn this duration was varied from 3 to 4 days with an average of 3.05 ± 0.05 days similarly in case of hybrid corn, this duration was varied from 3 to 5 days with an average of 4.25 ± 0.12 days (Table 4.4). According to Igyuve *et al.* (2018) the mean duration of fifth instar larvae was 2.0 days on maize crop. Sharanabasappa *et al.* (2018) noted the duration of fifth instar larvae as 2 to 3 days with an average of 2.40 ± 0.49 days on maize crop.

The width of head capsule of fifth instar larvae was varied from 1.97 to 2.01 mm with an average of 1.99 ± 0.003 mm, 1.99 to 2.03 mm with an average of 2.01 ± 0.003 mm, 1.99 to 2.03 mm with an average of 2.01 ± 0.003 mm, when insect was reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.5) (Fig.4.2). The head capsule width of fifth instar was measured 1.87 to 2.05 mm with an average of 1.96 ± 0.06 mm by Sharanabasappa *et al*. (2018). Igyuve *et al.* (2018) noted the head capsule width as 2.0 mm of fifth instar of *S. frugiperda*.

4.1.1.2.6 Sixth instar

Sixth instar larvae were observed similar to their previous instars but they were increased in size (Fig.4.1). They were brownish to blackish in colour similarly as recorded by Sharanabasappa *et al.* (2018) on maize crop.

The length of sixth instar larvae was varied from 31.7 to 34.9 mm with an average of 33.18 ± 0.25 mm for fodder corn. For the sweet corn the length of sixth instar larvae was varied from 31.8 to 32.3 mm with an average of 33.47 ± 0.20 mm. For the hybrid corn the length of sixth instar larvae was varied from 30.5 to 34.1 mm with an average of 32.19 ± 0.25 mm (Table 4.3). Sixth instar larvae attain length of 34.2 mm on maize crop (Igyuve *et al.*, 2018). The body length of full grown larvae was observed about 1 to ½ inches (38.0 mm) long (CABI, 2019).

The duration of sixth instar larvae was varied from 3 to 5 days with an average of 4.00 ± 0.07 days for fodder corn. In case of sweet corn this duration is varied from 3 to 5 days with an average of 4.30 ± 0.12 days similarly in case of hybrid corn, this duration is varied from 3 to 5 days with an average of 4.70 ± 0.12 days (Table 4.4). According to Igyuve *et al.* (2018) the mean duration of sixth instar larvae was 3.7 days on maize crop. Sharanabasappa *et al.* (2018) noted the duration of sixth instar larvae as 4 to 6 days with an average of 4.50 ± 0.50 days on maize crop.

Table 4.3: Length of different instars of *S. frugiperda* on various genotypes of maize crop

S.N.	Genotypes	Length of larval instars (mm)																	
		I			II			III			IV			V			VI		
		Min	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**
1.	Fodder corn(African tall)	0.8	1.3	1.20±0.02	2.1	3.7	2.56±0.10	5.5	6.3	5.86±0.04	9.2	10.3	9.74±0.08	15.4	16.5	16.07±0.06	31.7	34.9	33.18±0.25
2.	Sweet corn(Sugar 75)	1	1.9	1.31±0.04	2.7	3.2	3.08±0.02	5.8	6.9	6.21±0.07	9.7	10.8	10.08±0.06	15	16.8	16.42±0.12	31.8	32.3	33.47±0.20
3.	Hybrid(PRO-4212)	1	1.9	1.37±0.05	2	3.9	3.11±0.07	5.1	6.8	5.92±0.14	9.1	10.7	9.97±0.12	15.3	17.2	16.01±0.14	30.8	34.1	32.19±0.25
	SE (m)±			0.045			0.076			0.097			0.095			0.117			0.241
	CD (5%)			0.129			0.215			0.275			0.27			0.332			0.684

Table 4.4: Duration of larval instars of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Duration of larval instars (Days)																	
		I			II			III			IV			V			VI		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(African tall)	2	2	2.00±0.00	2	4	2.95±0.08	2	3	2.05±0.05	2	3	2.15±0.08	3	4	3.10±0.06	3	5	4.00±0.07
2.	Sweet corn(Sugar 75)	2	2	2.00±0.00	2	4	3.00±0.07	2	3	2.10±0.06	2	3	2.10±0.06	3	4	3.05±0.05	3	5	4.30±0.12
3.	Hybrid(PRO-4212)	2	3	2.10±0.06	2	4	3.90±0.10	2	3	2.95±0.05	3	3	3.00±0.00	3	5	4.25±0.12	3	5	4.70±0.12
	SE (m)±			0.04			0.088			0.057			0.062			0.09			0.112
	CD (5%)			N.S.			0.249			0.162			0.175			0.25			0.319

N.S. = Non- Significant

Table 4.5: Head capsule width of *S. frugiperda* on different genotypes of maize

S.N.	Genotypes	Width of head capsule (mm)														
		I			II			III			IV			V		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(African tall)	0.31	0.36	0.34±0.003	0.41	0.46	0.43±0.003	0.71	0.76	0.74±0.003	1.26	1.31	1.29±0.003	1.97	2.01	1.99 ±0.003
2.	Sweet corn(Sugar 75)	0.34	0.38	0.36±0.003	0.44	0.48	0.46±0.003	0.74	0.78	0.76±0.003	1.29	1.33	1.31±0.003	1.99	2.03	2.01±0.003
3.	Hybrid (PRO-4212)	0.34	0.38	0.36±0.003	0.44	0.48	0.46±0.003	0.74	0.78	0.76±0.003	1.29	1.33	1.31±0.003	1.99	2.03	2.01±0.003
	SE (m)±			0.003			0.003			0.003			0.003			0.003
	CD (5%)			0.008			0.008			0.008			0.008			0.008

4.1.1.2.7 Total larval period

The total larval period varied from 15 to 18 days with an average of 16.25 ± 0.17 days, 16 to 18 days with an average of 16.65 ± 0.16 days, 16 to 21 days with an average of 20.25 ± 0.29 days, when the insects were reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.6).

The larval period tends to be about 14 – 30 days has been reported (Pitre and Hogg, 1983), 14 to 19 days (Sharanabasappa *et al.*, 2018) in maize crop, which may fluctuated by weather condition. The total larval period of *S. frugiperda* was 14 days in summer and 30 days in winter in maize crop (Igyuve *et al.*, 2018).

Table 4.6: Total larval period of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Total larval period (Days)		
		Min	Max	Mean ± SD
1.	Fodder corn(African tall)	15	18	16.25±0.17
2.	Sweet corn(Sugar 75)	16	18	16.65±0.16
3.	Hybrid corn(PRO-4212)	16	21	20.25±0.29
	SE (m) ±			0.222
	CD (5%)			0.630

4.1.1.2.8 Larval survival rate

The larval survival rate was recorded 85 to 100 per cent with an average of 97.0 ± 3.0 per cent, 90 to 100 per cent with an average of 97.0 ± 2.0 per cent, 80 to 95 per cent with an average of 87.0 ± 2.5 per cent from total of 20 larvae of *S. frugiperda,* when reared in fodder corn, sweet corn and hybrid corn respectively (Table 4.7).

Table 4.7: Larval survival rate of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Larvae survival rate (%)		
		Min	Max	Mean ± SE
1.	Fodder corn(African tall)	85	100	97.00±3.00
2.	Sweet corn(Sugar 75)	90	100	97.00±2.00
3.	Hybrid corn(PRO-4212)	80	95	87.00±2.55
	SE (m)±			2.550
	CD (5%)			7.943

4.1.1.3 Pre-pupa

When the larvae became full grown, they stopped feeding and became darker and wrinkled, contracted their body and finally stopped feeding and other activities and this stage was considered as pre- pupal stage. The colour of body changed to light green, during the pre-pupal stage in all the genotypes *viz.* fodder corn, sweet corn and hybrid corn. (Fig.4.1)

The length of the pre- pupae ranged from 19 to 22 mm with an average of 20.0 ± 0.11 mm while the breadth ranged from 2.7 to 3.2 mm with an average of 3.08 ± 0.02 mm, when the insect reared in fodder corn. In case of sweet corn, the length of the pre- pupae ranged from 19 to 23 mm with an average of 20.9 ± 0.27 mm, while the breadth ranged from 2.5 to 3.5 mm with an average of 3.11 ± 0.04 mm but in hybrid corn the length of the pre- pupae ranged from 19 to 24 mm with an average of 21.0±0.37 mm while the breadth ranged from 2.3 to 3.5 mm with an average of 2.64 ± 0.07 mm. (Table 4.8)

Table 4.8: Measurement of pre-pupal stage of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Size (mm)					
		Min		Max		Mean ± SD	
		Length	Breath	Length	Breath	Length	Breath
1.	Fodder corn(African tall)	19	2.7	22	3.2	20.0±0.11	3.08±0.02
2.	Sweet corn(Sugar 75)	19	2.5	23	3.5	20.9±0.27	3.11±0.04
3.	Hybrid corn(PRO-4212)	19	2.3	24	3.5	21.0±0.37	2.64±0.07
	SE (m)±					0.273	0.052
	CD (5%)					0.774	0.148

The pre- pupal stage duration varied from 1 to 2 days, with an average of 1.95±0.05 days, when *S. frugiperda* was reared in fodder corn. In case of sweet corn, the duration of this period ranged from 2 to 3 days with an average of 2.10±0.06 days but when the insect was reared in hybrid corn, the pre- pupal stage duration varied from 2 to 3 days, with an average of 2.95±0.05 days. (Table 4.9)

Table 4.9: Duration of pre-pupal stage of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Duration (days)		
		Min	Max	Mean ± SD
1.	Fodder corn(African tall)	1	2	1.95±0.05
2.	Sweet corn(Sugar 75)	2	3	2.10±0.06
3.	Hybrid corn(PRO-4212)	2	3	2.95±0.05
	SE (m) ±			0.057
	CD (5%)			0.162

4.1.1.4 Pupa

4.1.1.4.1 Colour, shape and size

The newly developed pupa of *S. frugiperda* was soft and greenish in colour. After some times, the pupa turned into shiny reddish brown colour. The pupa were broadly rounded from the anterior side and tapered from the posterior side. A sharp spine was also present at the posterior end (Fig.4.1). All the observations were similar in all the genotypes *viz.* fodder corn, sweet corn and hybrid corn. Similarly the pupa was found reddish brown in colour, when reared in maize crop (Igyuve *et al.,* 2018).

The length of pupae was ranged from 13 to 16 mm with an average of 14.3 ± 0.23 mm, while the breadth was varied from 3.2 to 4.5 mm with an average of 4.22 ± 0.07 mm, when the fodder corn was selected as host of *S. frugiperda*. In case of sweet corn, the length of pupae was ranged from 13 to 17 mm with an average of 14.7 ± 0.31 mm, while the breadth was varied from 3.0 to 4.5 mm, with an average of 4.22 ± 0.07 mm but the length of pupae was ranged from 14 to 17 mm with an average of 15.2 ± 0.23 mm, while the breadth was varied from 3.3 to 4.5 mm with an average of 4.16 ± 0.07 mm, when the insect was reared in hybrid corn. (Table 4.10)

Table 4.10: Size of pupa of *S. frugiperda* (J.E Smith) on different genotypes of maize crop.

S.N.	Genotypes	Length of pupa (mm)			Breadth of pupa (mm)		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD
1	Fodder corn(African tall)	13	16	14.3±0.23	3.2	4.5	4.22±0.07
2	Sweet corn(Sugar 75)	13	17	14.7±0.31	3.0	4.5	4.22±0.07
3	Hybrid corn(PRO-4212)	14	17	15.2±0.23	3.3	4.5	4.16±0.07
	SE (m) ±			0.265			0.075
	CD (5%)			0.753			NS

N.S. = Non- Significant

4.1.1.4.2 Morphometric difference in male and female pupa

Pupal sexing can be done by looking at the genital opening. The distance between genital opening and anal slot can be used to distinguish the female and male pupa. The distance between genital opening and anal slot was recorded more in case of female than the male in all the genotypes *viz.* fodder corn, sweet corn and hybrid corn.

4.1.1.4.3 Pupal period

The duration of pupal stage was varied from 6 to 9 days, with an average of 6.65 ± 0.22 days, when *S. frugiperda* was reared in fodder corn. In case of sweet corn, the duration of this period was ranged from 5 to 8 days with an average of 6.30 ± 0.14 days but when the insect was reared in hybrid corn, the pupal stage duration was varied from 6 to 9 days, with an average of 6.95 ± 0.15 days. (Table 4.11)

Murua *et al.* (2008) noted the average pupal period of *S. frugiperda* was 9.28 ± 0.16 days on corn crop. Pupal period was ranged from 9.0 to 12.0 days with an average of 10.50±1.28 days (Sharanabasappa *et al.,* 2018). Duration of the pupa stage was recorded eight to nine days during the rainy season, but reaches 20 to 30 days during the winter (Igyuve *et al.,* 2018). The pupal stage duration was noted about 8 to 9 days in summer and about 20 to 30 days in cool season, which may fluctuate by the weather conditions (CABI, 2019).

Table 4.11: Pupal period of *S. frugiperda* in different genotypes of maize crop

S.N.	Genotypes	Pupal Period (Days)		
		Min	Max	Mean ± SD
1	Fodder corn(African tall)	6	9	6.65±0.22
2	Sweet corn(Sugar 75)	5	8	6.30±0.14
3	Hybrid corn(PRO-4212)	6	9	6.95±0.15
	SE (m) ±			0.177
	CD (5%)			0.502

4.1.1.5 Adult

4.1.1.5.1 Colour, appearance and size

The forewings of female were less conspicuous, ranging from uniform grayish brown to delicate gray and brown spots. The male forewings were shaded with brown and gray scales, with a white triangular patch in the apical region and a circular spot in the middle of the wing. The hind wing was silver-white in both male and female, with a narrow dark margin. The size of female moth was slightly bigger than the male once (Fig. 4.1). The morphological characters of adult of *S. frugiperda* are similar as reported earlier (Oliver and Chapin, 1981 and Sharanabasappa *et al*., 2018).

The length of male moths ranged from 10 to 15 mm with an average of 13.2 ± 1.6 mm, while the length of female moths ranged from 16 to 21 mm with an average of 19 ± 1.4 mm, when the fodder corn was selected as host of *S. frugiperda*. In case of sweet corn, the length of male moths ranged from 10 to 17 mm with an average of 12.9 ± 1.8 mm, while the length of female moths ranged from 18 to 22 mm with an average of 20.1 ± 1.0 mm but the length of male moths ranged from 10 to 16 mm with an average of 12.2 ± 1.5 mm, while the length of female moths ranged from 17 to 23 mm with an average of 19.7 ± 1.6 mm when the insect was reared in hybrid corn. (Table 4.12)

Adult male was smaller than female having 1.6 cm of body length, while the body length of female moth was reported 3.8 cm (Bhusal and Chapagain, 2020).

Table 4.12: Body length of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Body length (mm)					
		Female			Male		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(African tall)	16	21	19.00±0.32	10	15	13.85±0.20
2.	Sweet corn(Sugar 75)	18	22	20.20±1.72	10	16	13.55±0.32
3.	Hybrid corn(PRO-4212)	17	23	19.55±0.35	10	16	12.20±0.39
	SE (m)±			0.293			0.317
	CD (5%)			0.833			0.901

4.1.1.5.2 Wingspan

The wingspan of male moths ranged from 3.0 to 3.4 cm with an average of 3.2 ± 0.1 cm, while the wingspan of female moths ranged from 3.0 to 3.5 cm with an average of 3.3 ± 0.1 cm, when the fodder corn was selected as host of *S. frugiperda*. In case of sweet corn, the wingspan of male moths ranged from 2.9 to 3.4 cm with an average of 3.1 ± 0.1 cm, while the wingspan of female moths ranged from 3.0 to 3.5 cm with an average of 3.2 ± 0.1 cm but the wingspan of male moths ranged from 3.0 to 3.3 cm with an average of 3.1 ± 0.1 cm, while the wingspan of female moths ranged from 3.1 to 3.5 cm with an average of 3.3 ± 0.1 cm when the insect was reared in hybrid corn. (Table 4.13)

Similarly the average wingspan of female moths of *S. frugiperda* was reported 3.20 cm with a range of 3.00 to 3.40 cm and it was 3.25 cm with a range of 3.00 to 3.50 cm in male moths (Sharanabasappa *et al.*, 2018). The moths of *S. frugiperda* have a wingspan of 32 to 40 mm (Igyuve *et al.,* 2018). Bhusal and Chapagain (2020) observed that the *S. frugiperda* have a wingspan of 3.7 cm for male and 3.8 cm for female.

Table 4.13: Wingspan of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Wingspan (cm)					
		Female			Male		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(African tall)	3.0	3.5	3.37±0.03	3.0	3.4	3.24±0.03
2.	Sweet corn(Sugar 75)	3.0	3.5	3.24±0.04	2.9	3.4	3.19±0.03
3.	Hybrid corn(PRO-4212)	3.1	3.5	3.37±0.02	3.0	3.3	3.12±0.02
	SE (m)±			0.036			0.032
	CD (5%)			0.103			0.09

4.1.1.5.3 Pre-oviposition period

The pre-oviposition period of female moths of *S. frugiperda* varied from 3 to 4 days with an average of 3.10 ± 0.06 days, 3 to 4 days with an average of 3.05 ± 0.05 days, 3 to 4 days with an average of 3.70 ± 0.10 days on fodder corn, sweet corn and hybrid corn respectively. (Table 4.14)

Similarly Murua *et al.* (2008) reported that the average pre-oviposition period of *S. frugiperda* was 3.50 ± 0.4 days on corn crop. Igyuve *et al.* (2018) and Prasanna *et al.* (2018) observed the pre-oviposition period of *S. frugiperda* as 3 to 4 days on maize crop. The pre-oviposition period was noted 3 to 4 days with an average of 3.6 ± 0.49 days on maize crop (Sharanabasappa *et al.,* 2018).

Table 4.14: Pre-ovipositional period of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Pre-oviposition period (Days)		
		Min	Max	Mean ± SD
1.	Fodder corn(African tall)	3	4	3.10±0.06
2.	Sweet corn(Sugar 75)	3	4	3.05±0.05
3.	Hybrid corn(PRO-4212)	3	4	3.70±0.10
	SE (m) ±			0.078
	CD (5%)			0.222

4.1.1.5.4 Oviposition period

The oviposition period of female moths of *S. frugiperda* was reported 2 days in all replication with an average of 2.00 ± 0.00 days, 1 to 2 days with an average of 1.85 ± 0.08 days, 2 days in all the replications with an average of 2.00 ± 0.00 days on fodder corn, sweet corn and hybrid corn, respectively. (Table 4.15)

According to Murua *et al.* (2008) the average oviposition period of *S. frugiperda* was 7.44 ± 0.96 days on corn crop. The oviposition period was noted 2 to 3 days with an average of 2.8 ± 0.40 days on maize crop (Sharanabasappa *et al.,* 2018).

Table 4.15: Ovipositional period of *S. frugiperda* on different genotypes of maize crop-

S.N.	Genotypes	Ovipositional period (Days)		
		Min	Max	Mean ± SD
1.	Fodder corn(African tall)	2	2	2.00±0.00
2.	Sweet corn(Sugar 75)	1	2	1.85±0.08
3.	Hybrid corn(PRO-4212)	2	2	2.00±0.00
	SE (m) ±			0.047
	CD (5%)			0.134

4.1.1.5.5 Post oviposition period

After completion of egg laying, the female moths of *S. frugiperda* lived for 3 to 5 days with an average post-oviposition period of 4.30 ± 0.12 days, 3 to 5 with an average of 4.00 ± 0.07 days, 3 to 5 days with an average of 4.60 ± 0.13 days on fodder corn, sweet corn and hybrid corn, respectively. (Table 4.16)

More or less similar the average post-oviposition period of *S. frugiperda* was 2.17 ± 0.48 days on corn crop. Similarly the post-oviposition period was observed 4 to 5 days with an average of 4.30 ± 0.46 days on maize crop (Sharanabasappa *et al.,* 2018).

Table 4.16: Post oviposition period of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Post oviposition Period (Days)		
		Min	Max	Mean ± SD
1.	Fodder corn(African tall)	3	5	4.30±0.12
2.	Sweet corn(Sugar 75)	3	5	4.00±0.07
3.	Hybrid corn(PRO-4212)	3	5	4.60±0.13
	SE (m) ±			0.115
	CD (5%)			0.326

4.1.1.5.6 Longevity

The longevity of male moths ranged from 5 to 7 days with an average of 6.1 ± 0.8 days, while the longevity of female moth ranged from 7 to 11 days with an average of 9.0 ± 1.0 days when *S. frugiperda* was reared in fodder corn. In case of sweet corn, the longevity of male moths was ranged from 5 to 7 days with an average of 6.1 ± 0.8 days, while the longevity of female moths of 7 to 11 days with an average of 9.2 ± 0.9 days, but when the insect was reared in hybrid corn, the longevity of male moths was varied from 5 to 7 days, with an average of 5.9 ± 0.8 days and for female moths this period was ranged from 7 to 12 days with an average of 9.2 ± 1.0 days. (Table 4.17)

In contrast Murua *et al*. (2008) observed the average longevity of female adult of *S. frugiperda* was 12.7 ± 1.03 days, while 16.6 ± 1.29 days for male adult on corn crop. According to Prasanna *et al.* (2018) the duration of adult life was reported about 7 to 12 days with an average of 10 days. The female adult survived for 10.80 days with a range of 9 - 12 days compared to male with a range of 7- 9 days with an average of 8.20 days (Sharanabasappa *et al.,* 2018).

Table 4.17: Adult longevity *of S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Adult longevity (Days)					
		Female			Male		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(African tall)	7	11	9.15±0.19	5	7	6.20±0.11
2.	Sweet corn(Sugar 75)	7	11	9.05±0.19	5	7	6.15±0.13
3.	Hybrid corn(PRO-4212)	7	12	9.20±0.22	5	7	6.60±0.13
	SE (m)±			0.207			0.128
	CD (5%)			NS			0.362

4.1.1.5.7 Fecundity

The egg laying capacity of female varied from 430 to 473 eggs with an average of 454.2 ± 2.73 eggs, 536 to 579 eggs with an average of 557.2 ± 2.81 eggs, 387 to 410 eggs with an average of 393.3 ± 5.79 eggs, when *S. frugiperda* was reared in fodder corn, sweet corn and hybrid corn, respectively. (Table 4.18)

Murua *et al.* (2008) noted that the average fecundity of female *S frugiperda* was 955.0 ± 149.0 eggs on corn crop. Igyuve *et al.* (2018) mentioned that the fecundity of female *S. frugiperda* was averages about 1500 with a maximum of over 2000 eggs per female on maize crop. Sharanabasappa *et al.* (2018) noted that each female laid 835 to 1169 eggs with an average of 1064.80 eggs.

Table 4.18: Fecundity of female adult of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	Average no. of eggs laid by a female		
		Min	Max	Mean ± SD
1.	Fodder corn(African tall)	430	473	454.2±2.73
2.	Sweet corn(Sugar 75)	536	579	557.2±2.81
3.	Hybrid corn(PRO-4212)	387	410	393.3±5.79
	SE (m) ±			4.039
	CD (5%)			11.469

4.1.1.5.8 Male female sex ratio

In the present investigation the sex ratio of male to female is highest on fodder corn (1:1.8) followed by hybrid corn (1:1.5) and sweet corn (1:1.2). It means that in each genotype of maize *viz*. fodder corn, sweet corn and hybrid corn the number of females were more than the number of male adults. (Table 4.19) There might be the nutrient factor which affect the ratio of male and female.

Similarly Murua *et al.* (2008) observed the sex ratio of male and female was 1:1.2 on corn, alfalfa as well as on soybean crop where the number of female adults was more than the number of male adults but in case of wheat M: F ratio was 1.2:1, where the number of male adults was more than female once and this ratio was 1:1 on weeds, where the ratio of male and female was equal.

Table 4.19: Sex ratio of male and female of *S. frugiperda* on different genotypes of maize crop

S.N.	Genotypes	No. of adults	Male	Female	M:F sex ratio
1.	Fodder corn (African tall)	20	07	13	1:1.80
2.	Sweet corn (Sugar 75)	20	09	11	1:1.20
3.	Hybrid corn (PRO-4212)	20	08	12	1:1.50

4.1.1.6 Total life span

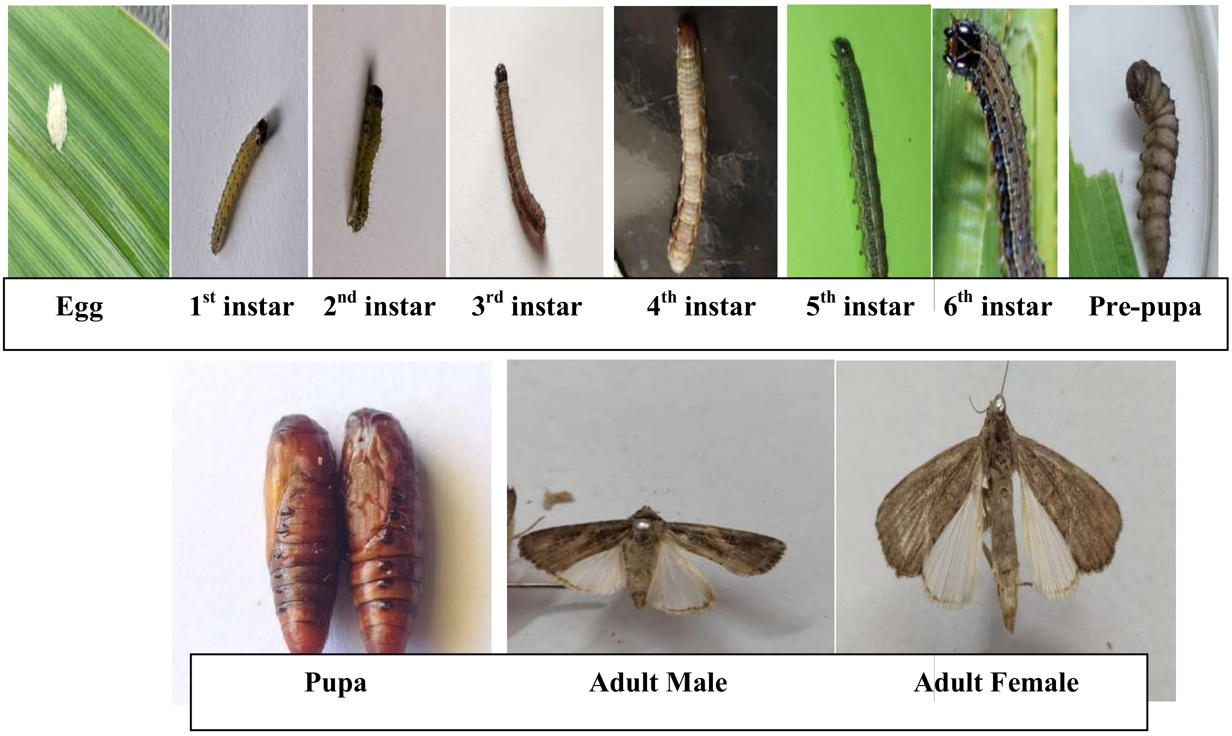
The total life cycle of *S. frugiperda* occupied on an average of 32.9 ± 0.82 days ranging from 27 to 41 days in case of male, while 35.9 ± 0.90 days ranging from 29 to 45 days in case of female, when *S. frugiperda* was reared in fodder corn. In case of sweet corn, the total life span of male moths was ranged from 28 to 41 days with an average of 33.1 ± 0.69 days, while the life span of female moths was varied from 30 to 45 days with an average of 36.0 ± 0.75 days, but when the insect was reared in hybrid corn, the life span of male moths was varied from 30 to 45 days, with an average of 40.3 ± 0.88 days and for female moths this period was ranged from 32 to 50 days with an average of 42.9 ± 0.97 days. (Table 4.20)

By the result it was concluded that there may be nutritional factor, which affect the life cycle of *S. frugiperda* on different host, viz. Fodder corn, sweet corn and hybrid corn.

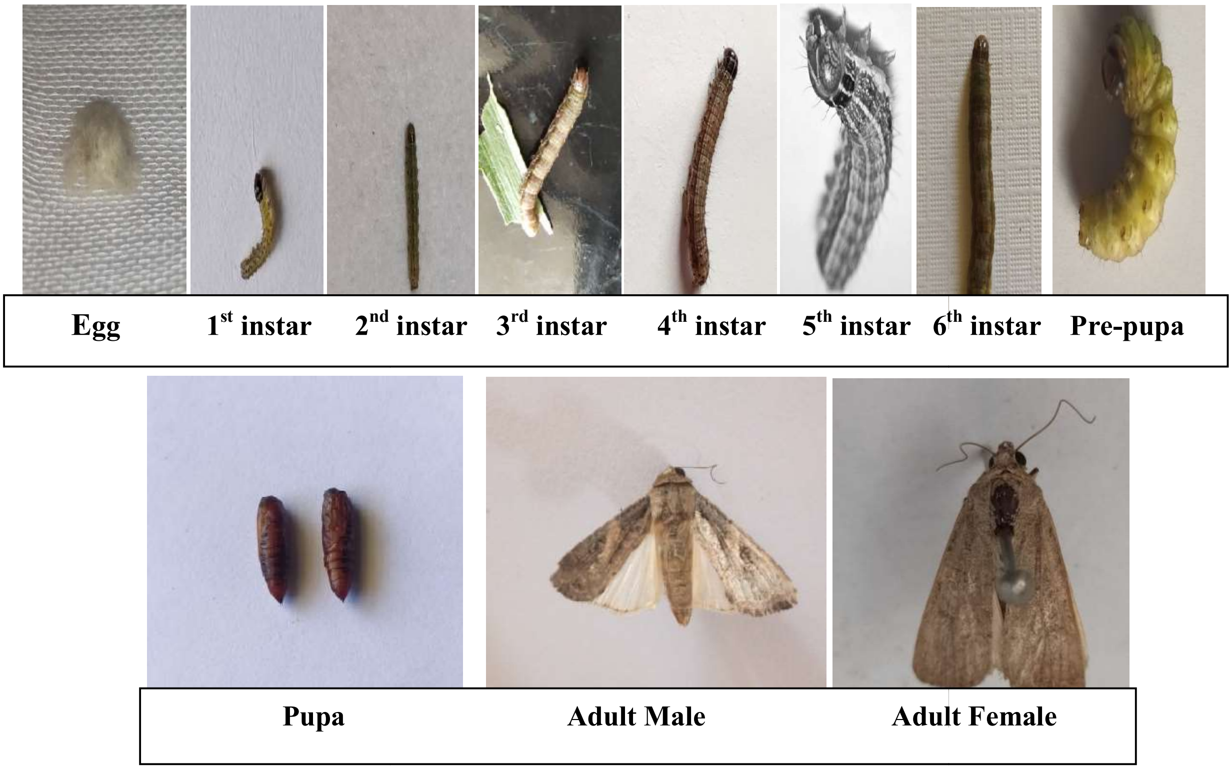
The life span of male moth of *S. frugiperda* ranged from 32 to 43 days with an average of 37.50 ± 5.00 days, while in case of female moth this period ranged from 34 to 46 days with an average of 40.50±4.88 days (Sharanabasappa *et al.*, 2018).

Table 4.20: Biology of fall armyworm, *Spodoptera frugiperda* reared on three different genotypes of maize crop

Stages	Duration								
	Fodder corn (African tall)			Sweet corn (Sugar 75)			Hybrid corn (PRO-4212)		
	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Incubation period	1	2	1.90±0.10	2	2	2.00±0.00	2	3	2.90±0.10
Larval period									
1st instar	2	2	2.00±0.00	2	2	2.00±0.00	2	3	2.10±0.06
2nd instar	2	4	2.95±0.08	2	4	3.00±0.07	2	4	3.90±0.10
3rd instar	2	3	2.05±0.05	2	3	2.10±0.06	2	3	2.95±0.05
4th instar	2	3	2.15±0.08	2	3	2.10±0.06	3	3	3.00±0.00
5th instar	3	4	3.10±0.06	3	4	3.05±0.05	3	5	4.25±0.12
6th instar	3	5	4.00±0.07	3	5	4.30±0.12	3	5	4.70±0.12
Pre-pupation period	1	2	1.95±0.05	2	3	2.10±0.06	2	3	2.95±0.05
Pupation period	6	9	6.65±0.22	5	8	6.30±0.14	6	9	6.95±0.15
Male longevity	5	7	6.20±0.11	5	7	6.15±0.13	5	7	6.60±0.13
Female longevity	7	11	9.15±0.19	7	11	9.05±0.19	7	12	9.20±0.22
Total life cycle (Egg to adult)									
Male	27	41	32.9±0.82	28	41	33.1±0.69	30	45	40.3±0.88
Female	29	45	35.9±0.90	30	45	36.0±0.75	32	50	42.9±0.97



Biology on fodder corn



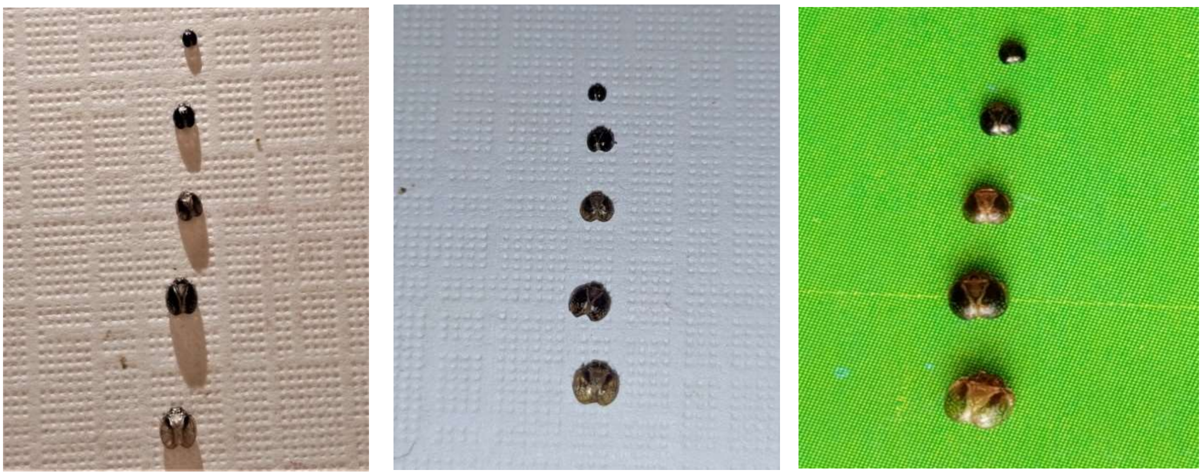
Biology on hybrid corn

Egg | 1st instar | 2nd instar | 3rd instar | 4th instar | 5th instar | 6th instar | Pre-pupa

Pupa | Adult Male | Adult Female

Biology on sweet corn

Fig. 4.1: Biology of *S. frugiperda* on different genotypes of maize crop.



A) Fodder corn **B) Sweet corn** **C) Hybrid corn**

Fig. 4.2: Head capsules of different stages of *S. frugiperda* on different genotypes of maize crop.

4.1.2 Behaviour of *S. frugiperda* on maize crop

Different behaviours of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) were evaluated on maize crop, under laboratory conditions (temperature = 25 ±2°C; RH = 60 ±10%) are as following-

4.1.2.1 Ovipositional preference behaviour

Plants of maize (5 leaf stage) provided many sites for oviposition. The experiment was repeated of ten times and it was observed that the female moths of *S. frugiperda* mainly preferred, upper and lower surface of leaf and whorl for their egg laying (Fig. 4.4). The egg masses were also found on the top section of the screen of cage, which was used for the covering of plant. The order of preference of ovipositional site was leaf whorl= screen < upper surface of leaf < lower surface of leaf (Fig.4.3). The egg masses were rarely found on the inner surface of the pots, which were holding the plants.

During the present investigation, it was observed that the lower surface of leaves was more preferred by female than any other sites of maize crop.

Meagher *et al.* (2011) noted that females of *S. frugiperda* placed more egg masses on the screen enclosure than on corn plants.

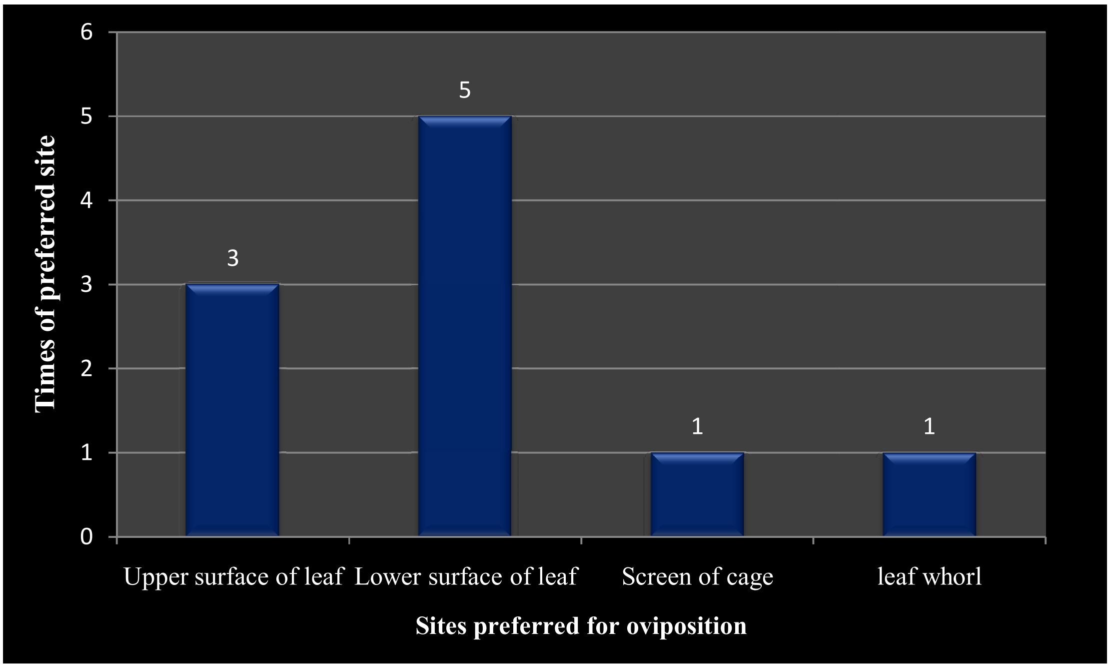


Fig. 4.3: Choice of oviposition sites of *Spodoptera frugiperda* on maize plant.

4.1.2.2 Neonate feeding preference behaviour

After 24 hours of release, neonate larvae of *S. frugiperda* were found feeding on all the genotypes of maize *viz*. fodder corn, sweet corn and hybrid corn under laboratory condition in separate petri dishes.

Significant differences in response of *S. frugiperda* to different genotypes were not prominent. After 24 hours of release the neonate larvae were more attracted to sweet corn and fodder corn, while hybrid corn was the least attractive food source as the larvae consumed lesser leaf of hybrid corn. The order of preference of hosts was hybrid corn < fodder corn < sweet corn. However, fodder corn was statistically on a par with hybrid corn with respect to feeding preference. (Table 4.21)

Silva *et al.* (2016) observed that the larvae exhibited an equal feeding preference for maize, soybean, cotton, and oat; wheat was the least attractive host, when five different crops were used as feeding host of *Spodoptera frugiperda* (J.E. Smith).

Table 4.21: Feeding preference of Neonate larvae of *S. frugiperda* with respect to different genotypes of maize crop.

S.N.	Hosts	Wt. of leaf consumed by larvae (g)								
		1st Day			2nd Day			3rd Day		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
1.	Fodder corn(J-1006)	0.018	0.049	0.039±0.003	0.051	0.079	0.062±0.002	0.079	0.095	0.087±0.002
2.	Sweet corn(Sugar 75)	0.031	0.048	0.041±0.001	0.063	0.078	0.068±0.002	0.082	0.106	0.094±0.002
3.	Hybrid corn(PRO-4212)	0.029	0.039	0.034±0.001	0.049	0.078	0.060±0.002	0.078	0.097	0.085±0.002
	SE (m)±			0.002			0.002			0.002
	CD (5%)			0.005			0.007			0.006

4.1.2.3 Larval dispersal behaviour

After hatching of eggs of *S. frugiperda*, emerged neonate were evaluated carefully and it was observed that the larvae were feeding in same position till 12 hours, and this duration is termed as pre-feeding movement phase. The larvae were started spreading randomly after pre-feeding phase. Some of the larvae were beginning to move to the upper surface of leaf from the lower surface of leaf. Initially the first instar larvae were consuming the leaf tissue from one side, leaving the opposite epidermal layer intact. Feeding by neonate caterpillars on the leaves resulting in semi-transparent patches, called as a 'window pan'. Young caterpillars were noted to spin through silken threads, by which they were able to move to the new plants. By the second and third instar, the larvae were completely separate, to reduce the risk of cannibalism as well as for the proper uptake of food and begin to make holes in leaves and eat from the edge of the leaves inward. As the larvae developed and their weight increased, they were unable to move through the silken threads and disperse through walking. The later instars were move permanently into the whorl. (Fig. 4.5)

4.1.2.4 Cannibalism behaviour

As predictable, the frequency of cannibalism increased with diminishing food quantity. In first treatment, when three larvae of fourth, fifth and sixth instar respectively were examined the cannibalism percent was found 66.6 per cent in each repetition with an average of 66.6 ± 0.00 percent. (Table 4.22) In second treatment, when two larvae of different age's *viz*. fifth and sixth instar were noticed, the range of cannibalism percent was 50 to 100 per cent with an average of 55.0 ± 4.5 percent. (Table 4.22) In third treatment, when two larvae of same age of sixth instar were examined the cannibalism percent was found 50 percent in each repetition with an average of 50.0 ± 0.00 percent. (Table 4.22) Rate of cannibalism of sixth instar larvae were greater when the potential victim were younger (Treatment 1^{st} & 2^{nd}) than when the larvae were same age (Treatment 3^{rd}). (Fig. 4.6)

Older individuals are more voracious cannibals than younger individuals and asymmetric encounters frequently result in cannibalism (Polis, 1981; Dial and Alder, 1990). The incidence of cannibalism on same age larvae varied throughout larval development, increasing substantially during fifth and sixth instar (Chapman *et al*., 1999).

Table 4.22: Comparison between cannibalism percent of different larval instars of *S. frugiperda*

S.N.	No. & instars of larvae	Percent of cannibalism		
		Min	**Max**	**Mean ± SD**
1.	3 (4th, 5th and 6th)	66.6	66.6	66.6±0.0
2.	2 (5th and 6th)	50	100	55.0±4.5
3.	2 (6th and 6th)	50	50	50.0±0.0
	SE (m)±			2.887
	CD (5%)			8.64

4.1.2.5 Mating behaviour

Preferred time and duration of mating of *S. frugiperda* were investigated in laboratory (Table 4.23). The experiment resulted that the mating occurred throughout the 24h cycle but majority of copulation started with evening hours and completed with night at between 6:00 pm to 10:00 pm. The duration of copulation was varied from 42 to 73 min with an average of 57.60 ± 3.49 min. Most matings (70%) lasted longer than 50min. The percent of fertile eggs was also observed in experiment and it was noted that the percent of fertile eggs was higher, when the mating duration was long than when the mating duration was relatively short, Which suggesting that the longer mating duration might be associated with transfer of more sperms that are used to increased the fertility of eggs. (Fig. 4.7)

Similarly, according to Simmons *et al.* (1992) in case of *Spodoptera frugiperda*, most matings (80%) lasted longer than 45 min. Mean duration of mating averaged 130 min.

Table 4.23: Percent of fertile eggs with respect to duration and preferred time for mating in moths of *S. frugiperda.*

S.N.	Duration (Min)	Time of mating (IST)	No. of eggs laid by female moth after mating	No. of fertile eggs	Percent of fertile eggs
1.	71	19:32 to 20:43	471	467	99.15
2.	47	08:07 to 08:54	262	203	77.48
3.	42	19:15 to 19:52	203	141	69.45
4.	60	20:31 to 21:31	293	270	92.15
5.	63	19:01 to 20:04	299	281	93.97
6.	57	20:37 to 21:34	279	245	87.81
7.	45	11:55 to 12:00	251	197	78.48
8.	73	18:11 to 19:24	493	491	99.59
9.	67	19:27 to 20:34	269	253	94.05
10.	51	19:53 to 20:44	271	230	84.87

Oviposition on lower surface of leaf.

Oviposition on upper surface of leaf.

Oviposition on covering screen

Oviposition on leaf whorl

Fig. 4.4: Ovipositional preference behaviour of *S. frugiperda.*

Pre feeding movement of larvae **Feeding on upper surface of leaf**

Silken thread formation by larvae **Movement towards the whorl**

Fig. 4.5: Larval dispersal behaviour of *S. frugiperda.*

Fig. 4.6: Cannibalism behaviour of FAW.

Fig. 4.7: Mating behaviour of FAW.

4.2 Studies on parasitoids of different stages of fall armyworm in laboratory conditions.

10 larvae of second instar onwards were collected weekly from the field along with the leaf and it was kept in petri dishes separately. The larvae were allowed to complete their larval period. The process was started from the infestation of fall armyworm and continued till it infestation persists. Total nine parasitoids were observed during the entire study period, four in diptera, four in hymenoptera and one was unidentified (Table 4.24). (Fig. 4.8)

Table 4.24: Parasitoid of *S. frugiperda* recorded on maize crop during kharif, 2019.

S.N.	Scientific name	Order	Family	Type of parasitization
1	*Chelonus sp.*	Hymenoptera	Braconidae	Egg-larval parasite
2	*Cotesia sp.*	Hymenoptera	Braconidae	Larval parasite
3	*Bracon sp.*	Hymenoptera	Braconidae	Larval parasite
4	*Meteorus sp.*	Hymenoptera	Braconidae	Larval parasitoid
5	*Ischiodon scutellaris*	Diptera	Syrphidae	Pupal parasitoid
6	Unidentified sp. of Tachinid fly	Diptera	Tachinidae	Larval parasitoid
7	*Buquetia musca*	Diptera	Tachinidae	Larval parasitoid
8	*Helophilus sp.*	Diptera	Syrphidae	Larval parasitoid
9	*Phaonia sp.*	Diptera	Muscidae	Larval parasitoid
10	Unidentified species			Egg parasitoid

In the group of ten parasitoids of *S. frugiperda*, larval parasitoids are in more numbers than other stage parasitoids. Among them *Cotesia sp.* (Hymenoptera: Braconidae) are more in numbers and observed in maize field from second week of sowing up to maturity of the crop.

During the study period one egg parasitoid, one egg larval parasitoid, six larval parasitoids and one pupal parasitoid were observed on fall armyworm. Identification of above parasitoids was done by available picture in networking sites and literature.

According to Ochoa *et al.* (2003) *Chelonus sp.* had the broadest parasitoid on fall armyworm on maize crop during their investigation. Sisay *et al.* (2019) reported five different species of parasitoids of FAW eggs and larvae and among them, *Cotesia icipe* (Hymenoptera: Braconidae) was the major one was followed by *Chelonus curvimaculatus* (Hymenoptera: Braconidae). Meagher *et al.* (2015) reported two most common parasitoids that emerged from larvae, were the solitary endoparasitoids *Cotesia marginiventris* (Hymenoptera: Braconidae) and *Chelonus insularis* (Hymenoptera: Braconidae).

Larva of *Chelonus sp.*

Adult of *Chelonus sp.*

Pupa and adult of *Cotesia sp.*

Infected larva of FAW by *Bracon sp*.

Adult of *Meteorus sp.*

Adult of *Ischiodon scutellaris*

Pupa of unidentified sp of tachinid fly

Adult of unidentified sp. of tachinid fly

Adult of *Buquetia musca*

Adult of *Helophilus sp.*

Infected larva of FAW by *Phaonia sp.*

Adult of *Phaonia sp.*

Unidentified species

Fig. 4.8: Parasitoids of different stages of *S. frugiperda* observed in laboratory condition.

4.3 Relative efficacy of different bio-rational insecticides against fall army worm on maize crop.

A field experiment was conducted at Research Cum instructional farm at Indira Gandhi Krishi Vishwavidhyalaya, Raipur (C.G.) under natural field conditions to evaluate the bio-efficacy of some bio-rational insecticides against fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on maize crop. The investigation for evaluating the bio-efficacy of eight bio-rational insecticides *viz*. Spinetoram 11.7% SC @ 0.3 ml per lit, Chlorantraniliprole 18.5%SC @ 3.0 ml per lit, Emamectin benzoate 5% SG @ 0.5 g per lit, Pyriproxifen 10% EC @ 1.0 ml per lit, *Beaveria bassiana* @ 4.0 g per lit, Azadirachtin 0.15 EC @ 4.0 ml per lit, Buprofezin 25% SC @ 1.6 ml per lit and *Bacillus thuringiensis* @ 1.5 ml per lit of water was carried out during kharif 2019. The experiment was laid out in randomize block design with three replications along with its untreated check for comparison.

The larval population of fall armyworm was recorded first. The average larval population was recorded from randomly selected five plants from each plot, one day before the application of insecticides as pre-treatment observations and after one, three and seven days as post-treatment observations. Second and third sprays were given after 15 and 45 days of first spray, respectively. Grain yield was also evaluated from each plot, individually and converted into quintal per hectare.

All the tested bio-rational insecticides were found significantly better over untreated control check in reducing the population of larvae of fall armyworm. Among the bio-rational insecticides, Spinetoram 11.7% SC @ 0.3 ml/lit was proved to be the best in comparison to other tested insecticides in decreasing the larval population of fall armyworm at each observation days with significantly highest grain yield (35.41 q/ha). The next insecticide was Chlorantraniliprole 18.5% SC @ 3.0 ml/lit, in efficacy for the management of fall armyworm with grain yield (34.31 q/ha).

4.3.1 Larval population reduction per five plants before and after the application of bio-rational insecticides

All the tested insecticides were found significantly better over control plot in reducing the population of larvae at each observation days after application.

Effect of bio-rational insecticides on the larvae of *S. frugiperda* after first spray

Pre-treatment observations

In pre-treatment observation, the population of fall armyworm larvae varied from 19.33 to 21.66 larvae per five plants and was non- significant among different treatments.

Post-treatment observations

Larval population at one day after first spray

After one day of first spray, the population of larvae of *S. frugiperda* on maize crop ranged in different treatments from 5.33 to 21 larvae per five plants.

The data presented in table 4.25 and depicted in Fig.4.9 revealed that among the different insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 5.33 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (9.66), Emamectin benzoate 5% SG @ 0.5 g/lit (10.66) but variate significantly from Buprofezin 25% SC @ 1.6 ml/lit (13), Pyriproxifen 10% EC @ 1.0 ml/lit (13.33), Azadirachtin 0.15 EC @ 4.0 ml/lit (13.33), *Bacillus thuringiensis* @ 1.5 ml/lit (13.66) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (14.66) as against 21 larvae per five plants in untreated control plot.

Larval population at three days after first spray

After three days of first spray, the population of larvae of *S. frugiperda* on maize crop varied in various treatments from 2.33 to 21.66 larvae per five plants.

The data presented in table 4.25 and depicted in Fig.4.9 revealed that among all tested insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 2.33 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (7.66), Emamectin benzoate 5% SG @ 0.5 g/lit (8.66) but variate significantly from Buprofezin 25% SC @ 1.6 ml/lit (12.33), Pyriproxifen 10% EC @ 1.0 ml/lit (13.0), Azadirachtin 0.15 EC @ 4.0 ml/lit (13.0), *Bacillus thuringiensis* @ 1.5 ml/lit (14.33) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (14.33) as against 21.33 larvae per five plants in untreated control plot.

Larval population at seven days after first spray

After seven days of first spray, the population of larvae of *S. frugiperda* on maize crop varied in various treatments from 5.33 to 21.0 larvae per five plants.

The data presented in table 4.25 and depicted in Fig.4.9 revealed that among all tested insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 5.33 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (10.0), Emamectin benzoate 5% SG @ 0.5 g/lit (12.0), Buprofezin 25% SC @ 1.6 ml/lit (12.0), Pyriproxifen 10% EC @ 1.0 ml/lit (13.0) but variate significantly from, Azadirachtin 0.15 EC @ 4.0 ml/lit (12.33), *Bacillus thuringiensis* @ 1.5 ml/lit (17.0) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (18.33) as against 21.0 larvae per five plants in untreated control plot.

Over all mean larval population of *Spodoptera frugiperda* (J. E. Smith)

Mean larval population of *S. frugiperda* on maize crop varied in various treatments from 4.33 to 21.11 larvae per five plants, which were randomly selected.

During the first spray the mean larval population was recorded which showed that, among the various bio- rational insecticides, T_1- Spinetoram 11.7%SC @ 0.3 ml/lit recorded the minimum population with 4.33 larvae per five plants, followed by T_{2-} Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (9.10), T_3 - Emamectin benzoate 5% SG @ 0.5 g/lit (10.44), T_7 - Buprofezin 25% SC @ 1.6 ml/lit (12.44), T_4 - Pyriproxifen 10% EC @ 1.0 ml/lit (12.77), T_6 - Azadirachtin 0.15 EC @ 4.0 ml/lit (12.99), T_8 - *Bacillus thuringiensis* @ 1.5 ml/lit (14.99) and it was maximum in T_5 - *Beaveria bassiana* @ 4.0 g/lit, 15.77 larvae per five plants.

Percent reduction of *Spodoptera frugiperda* (J. E. Smith) population over control

During first spray, percent reduction of *S. frugiperda* population was ranged from 25.29 to 79.48 percent in various treatments.

The overall maximum larval population reduction was recorded in T_1- Spinetoram 11.7%SC @ 0.3 ml/lit (79.48) treated plot, followed by T_{2-} Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (56.89), T_3 - Emamectin benzoate 5% SG @ 0.5 g/lit (50.54), T_7 - Buprofezin 25% SC @ 1.6 ml/lit (41.07), T_4 - Pyriproxifen 10% EC @ 1.0 ml/lit (39.5), T_6 - Azadirachtin 0.15 EC @ 4.0 ml/lit (38.46), T_8 - *Bacillus thuringiensis* @ 1.5 ml/lit (28.99) and lowest in T_5 - *Beaveria bassiana* @ 4.0 g/lit treated plot and was recorded only 25.29 percent reduction in insect population.

Table 4.25: Efficacy of bio-rational insecticides against *S. frugiperda* (J. E. Smith) in maize crop, after first spray

Treatments	Insecticides	Pre-treatment observation	Post-treatment observation			Mean	Percent reduction of insect population over control
			1 DAS	3 DAS	7 DAS		
T1	Spinetoram 11.7%SC	19.33 (4.5)	5.33 (2.5)	2.33 (1.82)	5.33 (2.5)	4.33	79.48
T2	Chlorantraniliprole 18.5%SC	19.66 (4.54)	9.66 (3.26)	7.66 (2.93)	10.0 (3.31)	9.10	56.89
T3	Emamectin benzoate 5%SG	21.33 (4.72)	10.66 (3.41)	8.66 (3.1)	12.0 (3.6)	10.44	50.54
T4	Pyriproxifen 10%EC	21.66 (4.75)	13.33 (3.75)	13.0 (3.71)	12.0 (3.59)	12.77	39.5
T5	*Beaveria bassiana*	20.0 (4.58)	14.66 (3.94)	14.33 (3.9)	18.33 (4.39)	15.77	25.29
T6	Azadirachtin 0.15%EC	20.33 (4.6)	13.66 (3.82)	13.0 (3.74)	12.33 (3.65)	12.99	38.46
T7	Buprofezin 25%SC	20.66 (4.64)	13.0 (3.73)	12.33 (3.63)	12.0 (3.76)	12.44	41.07
T8	*Bacillus thuringiensis*	21.0 (4.67)	13.66 (3.82)	14.33 (3.91)	17.0 (4.24)	14.99	28.99
T9	Untreated	20.33 (4.61)	21.0 (4.69)	21.33 (4.72)	21.0 (4.69)	21.11	-
	SE (m)±	0.182	0.174	0.148	0.116	-	-
	CD at 5%	NS	0.526	0.449	0.349	-	-

 # Figures in parentheses are square root transformed values.

Effect of bio-rational insecticides on the larvae of *S. frugiperda* after second spray

Pre-treatment observations

In pre-treatment observation, the population of fall armyworm larvae varied from 16.66 to 23.66 larvae per five plants and was non- significant among different treatments.

Post-treatment observations

Larval population at one day after second spray

After one day of second spray, the population of larvae of *S. frugiperda* on maize crop ranged in different treatments from 3.66 to 23 larvae per five plants.

The data presented in table 4.26 and depicted in Fig.4.10 revealed that among the different insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 3.66 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (11.0), Emamectin benzoate 5% SG @ 0.5 g/lit (12.0) but variate significantly from Buprofezin 25% SC @ 1.6 ml/lit (13.33), Pyriproxifen 10% EC @ 1.0 ml/lit (14.66), Azadirachtin 0.15 EC @ 4.0 ml/lit (15.0), *Bacillus thuringiensis* @ 1.5 ml/lit (15.66) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (16.33) as against 23 larvae per five plants in untreated control plot.

Larval population at three days after second spray

After three days of second spray, the population of larvae of *S. frugiperda* on maize crop varied in various treatments from 1.33 to 21.66 larvae per five plants.

The data presented in table 4.26 and depicted in Fig.4.10 revealed that among all tested insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 1.33 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (7.0), Emamectin benzoate 5% SG @ 0.5 g/lit (9.0) but variate significantly from Buprofezin 25% SC @ 1.6 ml/lit (10.33), Pyriproxifen 10% EC @ 1.0 ml/lit (11.0), Azadirachtin 0.15 EC @ 4.0 ml/lit (11.0), *Bacillus thuringiensis* @ 1.5 ml/lit (12.33) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (14.33) as against 21.66 larvae per five plants in untreated control plot.

Larval population at seven days after second spray

After seven days of second spray, the population of larvae of *S. frugiperda* on maize crop varied in various treatments from 4.33 to 20.66 larvae per five plants.

The data presented in table 4.26 and depicted in Fig.4.10 revealed that among all tested insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 4.33 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (9.0), Emamectin benzoate 5% SG @ 0.5 g/lit (11.0), Buprofezin 25% SC @ 1.6 ml/lit (12.33), Pyriproxifen 10% EC @ 1.0 ml/lit (12.33) but variate significantly from, Azadirachtin 0.15 EC @ 4.0 ml/lit (13.33), *Bacillus thuringiensis* @ 1.5 ml/lit (16.0) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (16.33) as against 20.66 larvae per five plants in untreated control plot.

Over all mean larval population of *Spodoptera frugiperda* (J. E. Smith)

Mean larval population of *S. frugiperda* on maize crop varied in various treatments from 3.10 to 21.77 larvae per five plants, which were randomly selected.

During the second spray the mean larval population was recorded which showed that, among the various bio- rational insecticides, T_1- Spinetoram 11.7%SC @ 0.3 ml/lit recorded the minimum population with 3.10 larvae per five plants, followed by T_{2}- Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (9.0), T_3 - Emamectin benzoate 5% SG @ 0.5 g/lit (10.66), T_7 - Buprofezin 25% SC @ 1.6 ml/lit (11.99), T_4 - Pyriproxifen 10% EC @ 1.0 ml/lit (12.66), T_6 - Azadirachtin 0.15 EC @ 4.0 ml/lit (13.11), T_8 - *Bacillus thuringiensis* @ 1.5 ml/lit (14.66) and it was maximum in T_5 - *Beaveria bassiana* @ 4.0 g/lit, 15.66 larvae per five plants.

Percent reduction of *Spodoptera frugiperda* (J. E. Smith) population over control

During second spray, percent reduction of *S. frugiperda* population was ranged from 28.06 to 85.76 percent in various treatments.

The overall maximum larval population reduction was recorded in T_1- Spinetoram 11.7%SC @ 0.3 ml/lit treated plot (85.76), followed by T_2 - Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (58.65), T_3 - Emamectin benzoate 5% SG @ 0.5 g/lit (51.03), T_7 - Buprofezin 25% SC @ 1.6 ml/lit (44.92), T_4 - Pyriproxifen 10% EC @ 1.0 ml/lit (41.84), T_6 - Azadirachtin 0.15 EC @ 4.0 ml/lit (39.77), T_8 - *Bacillus thuringiensis* @ 1.5 ml/lit (32.65) and lowest in T_5 - *Beaveria* *bassiana* @ 4.0 g/lit treated plot and was recorded only 28.06 percent reduction in insect population.

Table 4.26: Efficacy of bio-rational insecticides against *S. frugiperda* (J. E. Smith) in maize crop, after second spray

Treatments	Insecticides	Pre-treatment observation	Post-treatment observation			Mean	Percent reduction of insect population over control
			1 DAS	3 DAS	7 DAS		
T1	Spinetoram 11.7%SC	16.66 (4.19)	3.66 (2.15)	1.33 (1.52)	4.33 (2.3)	3.10	85.76
T2	Chlorantraniliprole 18.5%SC	18.33 (4.38)	11.0 (3.45)	7.0 (2.82)	9.0 (3.16)	9.0	58.65
T3	Emamectin benzoate 5%SG	20.66 (4.65)	12.0 (3.58)	9.0 (3.16)	11.0 (3.46)	10.66	51.03
T4	Pyriproxifen 10%EC	22.66 (4.86)	14.66 (3.95)	11.0 (3.43)	12.33 (3.63)	12.66	41.84
T5	*Beaveria bassiana*	21.33 (4.71)	16.33 (4.16)	14.33 (3.90)	16.33 (4.16)	15.66	28.06
T6	Azadirachtin 0.15%EC	20.66 (4.65)	15.0 (3.99)	11.0 (3.46)	13.33 (3.78)	13.11	39.77
T7	Buprofezin 25%SC	18.0 (4.33)	13.33 (3.78)	10.33 (3.34)	12.33 (3.62)	11.99	44.92
T8	*Bacillus thuringiensis*	22.0 (4.79)	15.66 (4.07)	12.33 (3.65)	16.0 (4.12)	14.66	32.65
T9	Untreated	23.66 (4.96)	23.0 (4.89)	21.66 (4.75)	20.66 (4.64)	21.77	-
	SE (m) ±	0.163	0.13	0.158	0.147	-	-
	CD at 5%	NS	0.393	0.477	0.444	-	-

 # Figures in parentheses are square root transformed values.

Effect of bio-rational insecticides on the larvae of *S. frugiperda* after third spray

Pre-treatment observations

In pre-treatment observation, the population of fall armyworm larvae varied from 4.20 to 5.73 larvae per five plants and was non- significant among different treatments.

Post-treatment observations

Larval population at one day after third spray

After one day of third spray, the population of larvae of *S. frugiperda* on maize crop ranged in different treatments from 1.33 to 3.46 larvae per five plants.

The data presented in table 4.27 and depicted in Fig.4.11 revealed that among the different insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 1.33 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (1.73) and Emamectin benzoate 5% SG @ 0.5 g/lit (1.73) but variate significantly from Pyriproxifen 10% EC @ 1.0 ml/lit (1.80), Buprofezin 25% SC @ 1.6 ml/lit (1.86), Azadirachtin 0.15 EC @ 4.0 ml/lit (1.86), *Bacillus thuringiensis* @ 1.5 ml/lit (2.00) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (2.06) as against 3.46 larvae per five plants in untreated control plot.

Larval population at three days after third spray

After three days of third spray, the population of larvae of *S. frugiperda* on maize crop varied in various treatments from 1.26 to 1.93 larvae per five plants.

The data presented in table 4.27 and depicted in Fig.4.11 revealed that among all tested insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit and Chlorantraniliprole 18.5% SC @ 3.0 ml/lit was found to be most effective, which recorded with 1.26 larvae per five plants. It was at par with Emamectin benzoate 5% SG @ 0.5 g/lit (1.40) but variate significantly from Pyriproxifen 10% EC @ 1.0 ml/lit (1.53), Buprofezin 25% SC @ 1.6 ml/lit (1.66), Azadirachtin 0.15 EC @ 4.0 ml/lit (1.66), *Bacillus thuringiensis* @ 1.5 ml/lit (1.66) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (1.86) as against 1.93 larvae per five plants in untreated control plot.

Larval population at seven days after third spray

After seven days of third spray, the population of larvae of *S. frugiperda* on maize crop varied in various treatments from 4.33 to 20.66 larvae per five plants.

The data presented in table 4.27 and depicted in Fig. 4.11 revealed that among all tested insecticides, Spinetoram 11.7%SC @ 0.3 ml/lit was found to be most effective, which recorded with 1.60 larvae per five plants. It was at par with Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (1.80), Emamectin benzoate 5% SG @ 0.5 g/lit (1.86), Buprofezin 25% SC @ 1.6 ml/lit (2.06), Pyriproxifen 10% EC @ 1.0 ml/lit (2.40) but variate significantly from, Azadirachtin 0.15 EC @ 4.0 ml/lit (2.13), *Bacillus thuringiensis* @ 1.5 ml/lit (2.13) and maximum population was recorded in plot treated with *Beaveria bassiana* @ 4.0 g/lit (2.26) as against 2.46 larvae per five plants in untreated control plot.

Over all mean larval population of *Spodoptera frugiperda* (J. E. Smith)

Mean larval population of *S. frugiperda* on maize crop varied in various treatments from 1.39 to 2.61 larvae per five plants, which were randomly selected.

During the third spray, the mean larval population was recorded which showed that, among the various bio- rational insecticides, T_1- Spinetoram 11.7%SC @ 0.3 ml/lit recorded the minimum population with 1.39 larvae per five plants, followed by T_2- Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (1.59), T_3 - Emamectin benzoate 5% SG @ 0.5 g/lit (1.66), T_7 - Buprofezin 25% SC @ 1.6 ml/lit (1.86), T_6 - Azadirachtin 0.15 EC @ 4.0 ml/lit (1.88), T_4 - Pyriproxifen 10% EC @ 1.0 ml/lit (1.91), T_8 - *Bacillus thuringiensis* @ 1.5 ml/lit (1.93) and it was maximum in T_5 - *Beaveria bassiana* @ 4.0 g/lit, 2.06 larvae per five plants.

Percent reduction of *Spodoptera frugiperda* (J. E. Smith) population over control

During third spray, percent reduction of *S. frugiperda* population was ranged from 21.07 to 46.74 percent in various treatments.

The overall maximum larval population reduction was recorded in T_1- Spinetoram 11.7%SC @ 0.3 ml/lit treated plot (46.74), followed by T_2 - Chlorantraniliprole 18.5% SC @ 3.0 ml/lit (39.08), T_3 - Emamectin benzoate 5% SG @ 0.5 g/lit (36.39), T_7 - Buprofezin 25% SC @ 1.6 ml/lit (28.73), T_6 - Azadirachtin 0.15 EC @ 4.0 ml/lit (27.96), T_4 - Pyriproxifen 10% EC @ 1.0 ml/lit (26.81), T_8 - *Bacillus thuringiensis* @ 1.5 ml/lit (26.05) and lowest in T_5 - *Beaveria* *bassiana* @ 4.0 g/lit treated plot and was recorded only 21.07 percent reduction in insect population.

More or less, similar findings were recorded by the various workers *viz.* Kubo and Klocke (1981), Adamczyk *et al.* (1999), Capalbo *et al.* (2001), Zamora *et al.* (2008), Laxmanrao (2009), Sharma *et al.* (2018), Hardke *et al.* (2011), Belay *et al.* (2012), Metzler and Mora (2017) etc. According to Kubo and Klocke (1981), Azadirachtin was proved to be useful by inhibition of ecdysis in test species. According to Adamczyk *et al.* (1999) the activity of Emamectin benzoate against 5th instar larvae of *Spodoptera frugiperda* was very high. After 48 hrs of application of *Bacillus thuringiensis* @ 200L/ha only dead, black larvae were found on maize crop but after twenty days of 1st application of *Bacillus thuringiensis* the same level of initial larvae infestation was recorded (Capalbo *et al.,* 2001). Application of Azadirachtin 1500 ppm showed least percent of mortality *i.e.*, 29.52 percent on first spray and 26.93 percent after second spray on lepidopteran larvae (Laxmanrao, 2009). According to Hardke *et al.* (2011), Chlorantraniliprole was found responsible for about more than 40 percent of mortality at 28th date after treatment. Spinetoram (11.7%) caused significantly higher (>60%) mortality in fall armyworm larvae after 16 hrs of application (Belay *et al.,* 2012). According to Metzler and Mora (2017), first application of Spinetoram, Solaris 6SC® (75ml/ha) significantly ($P<0.0001$) reduced the damage of *S. frugiperda* in comparison to the control with a reduction in plant damage from 32 to 1.3%.

Table 4.27: Efficacy of bio-rational insecticides against *S. frugiperda* (J. E. Smith) in maize crop, after third spray

Treatments	Insecticides	Pre-treatment observation	Post-treatment observation			Mean	Percent reduction of insect population over control
			1 DAS	3 DAS	7 DAS		
		(2.4)	(1.52)	(1.5)	(1.61)		
T2	Chlorantraniliprole 18.5%SC	5.26	1.73	1.26	1.8	1.5966667	39.08
		(2.5)	(1.65)	(1.5)	(1.67)		
T3	Emmamectin benzoate 5%SG	4.6	1.73	1.4	1.86	1.6633333	36.39
		(2.36)	(1.65)	(1.54)	(1.68)		
T4	Pyriproxyfen 10%EC	4.2	1.8	1.53	2.4	1.91	26.81
		(2.28)	(1.67)	(1.59)	(1.84)		
T5	*Beaveria bassiana*	4.26	2.06	1.86	2.26	2.06	21.07
		(2.29)	(1.75)	(1.69)	(1.8)		
T6	Azadirachtin 0.15%EC	4.13	1.86	1.66	2.13	1.8833333	27.96
		(2.26)	(1.69)	(1.63)	(1.76)		
T7	Buprofezin 25%SC	4.93	1.86	1.66	2.06	1.86	28.73
		(2.43)	(1.69)	(1.63)	(1.75)		
T8	*Bacillus thuringiensis* 8L	4.46	2	1.66	2.13	1.93	26.05
		(2.33)	(1.73)	(1.63)	(1.76)		
T9	Untreated	5.73	3.46	1.93	2.46	2.6166667	
		(2.59)	(2.11)	(1.71)	(1.86)		
	SE (m) ±	0.059	0.043	0.04	0.044		
	CD at 5%	NS	0.13	0.122	0.134		

 # Figures in parentheses are square root transformed values.

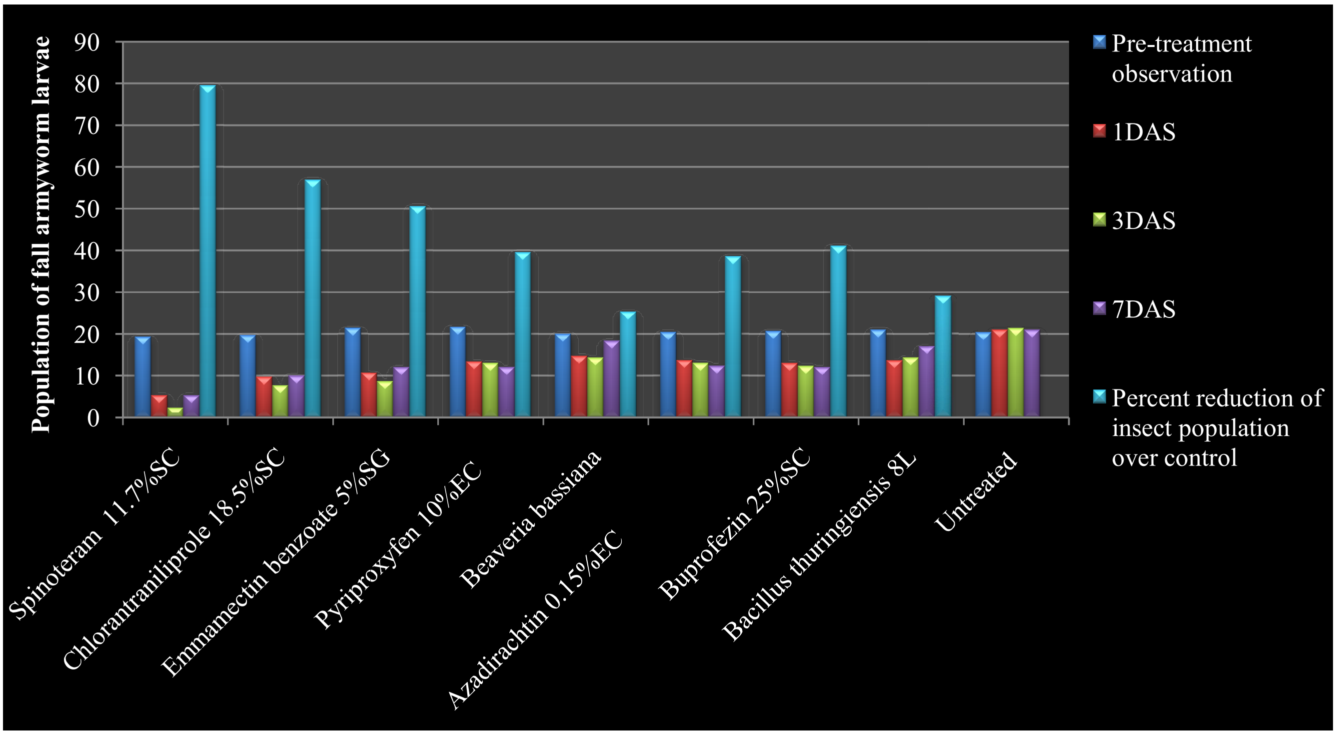


Fig.4.9: Percent reduction of population of *Spodoptera frugiperda* after first spray.

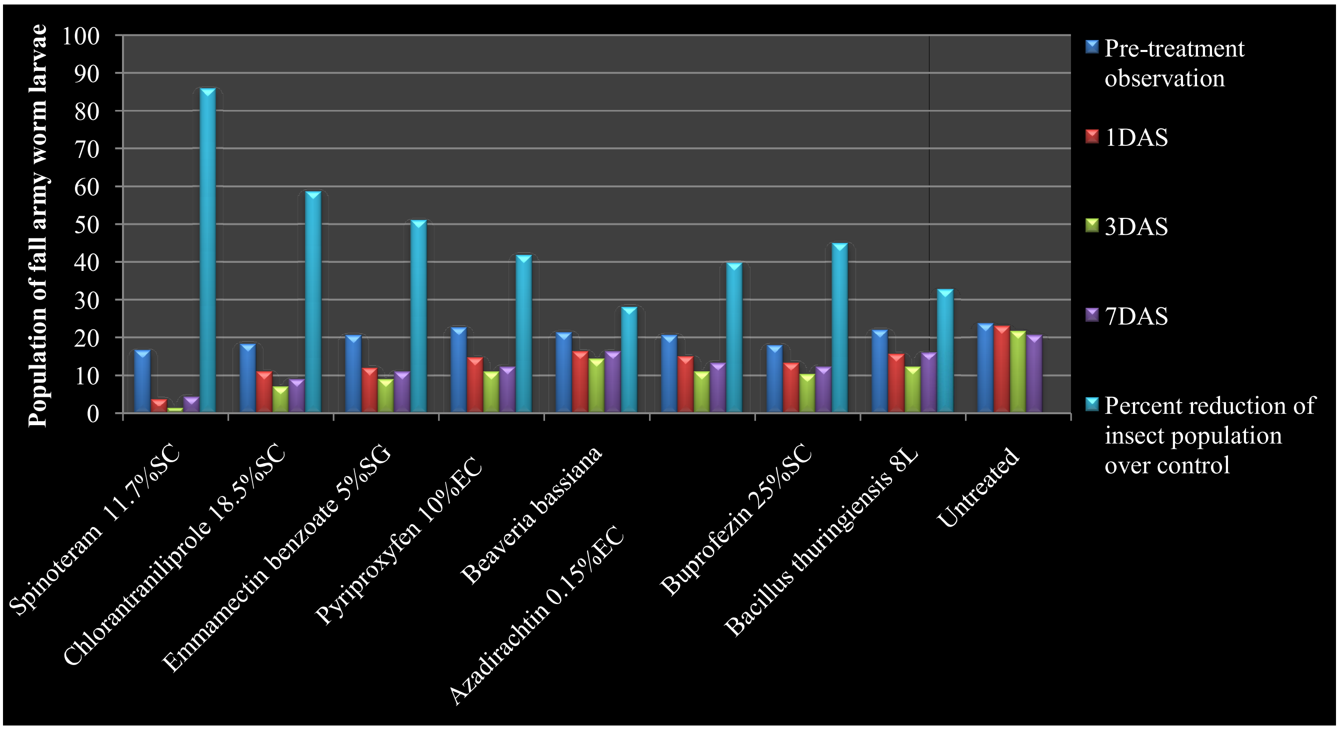


Fig. 4.10: Percent reduction of population of *Spodoptera frugiperda* after second spray.

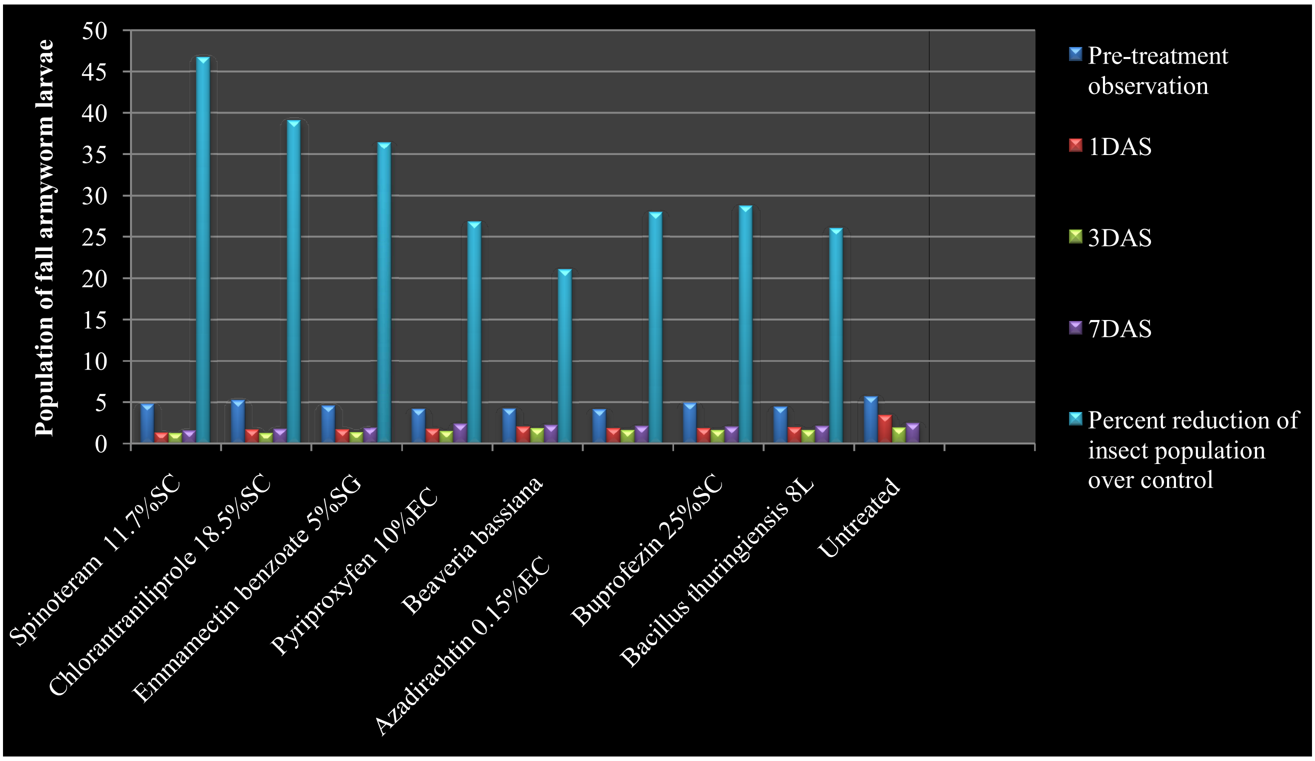


Fig. 4.11: Percent reduction of population of *Spodoptera frugiperda* after third spray.

4.3.2 Grain yield (q/ha)

The highest yield of grain was recorded in the plot, treated with Spinetoram 11.7% SC (35.41 q/ha), which was followed by Chlorantraniliprole 18.5% SC (34.31 q/ha), Emamectin benzoate 5% SG (32.18 q/ha), Buprofezin 25% SC (31.28 q/ha), Azadirachtin 0.15% EC (31.01 q/ha), Pyriproxifen 10% EC (30.50 q/ha) and *Bacillus thuringiensis* (28.50 q/ha), respectively, while the lowest grain yield of 28.10 q/ha was observed in plot treated with *Beaveria bassiana* and the untreated control plot resulted least grain yield (22.66 q/ha) in comparison to plots treated with different bio-rational insecticides. (Fig.4.12)

Present findings are more or less in accordance with the results of Belay *et al.* (2012) and Metzler and Mora (2017), who reported that Spinetoram 11.7% Sc and Chlorantraniliprole 18.5% SC were found to be most effective insecticides against the pest, fall armyworm.

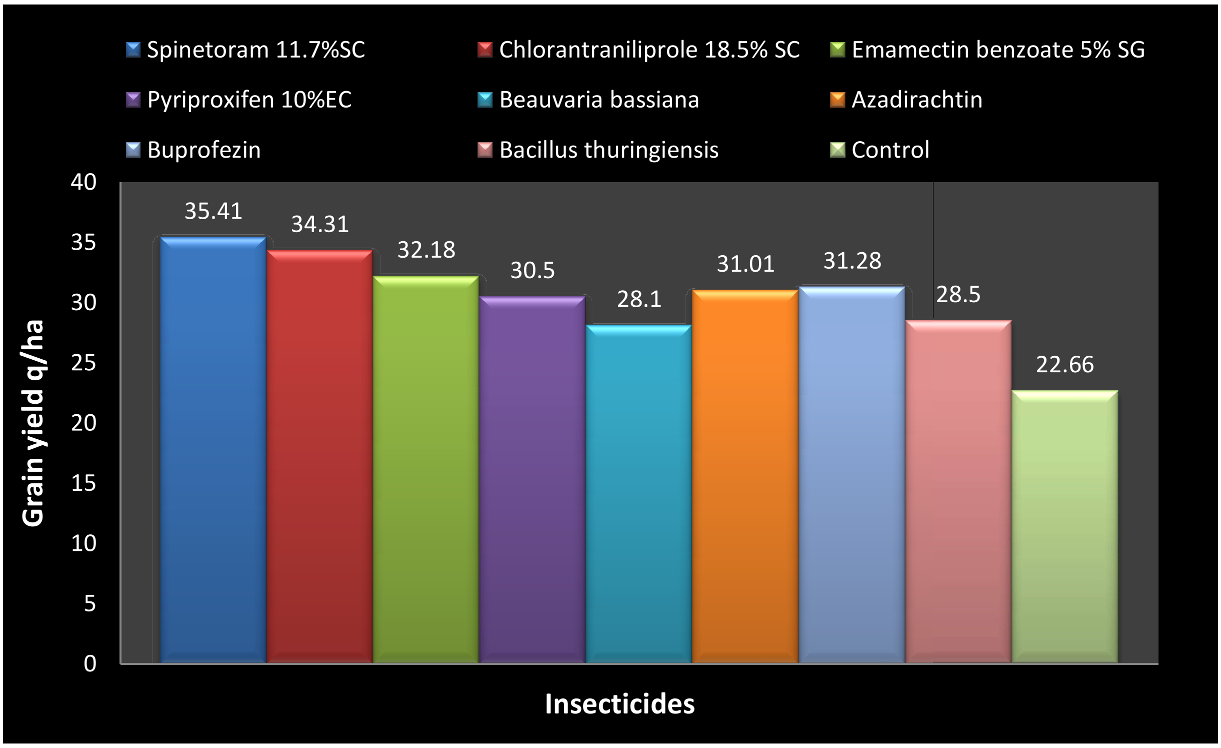


Fig. 4.12 : Grain yield of different bio-rational insecticides treated plots.

4.3.3 Economic estimation of different insecticides against fall armyworm on maize crop

The result of present investigations states that, all the treatments showed best in yield over control. The highest yield over control was obtained under the plot treated with Spinetoram 11.7% SC (12.75 q/ha), which was followed by Chlorantraniliprole 18.5% SC (11.65 q/ha) and Emamectin benzoate 5% SG (9.52 q/ha). Price of increased yield over control was calculated and the highest net profit was recorded with Spinetoram 11.7% SC (Rs.22440), which was followed by Chlorantraniliprole 18.5% SC (Rs.20504) and Emamectin benzoate 5% SG (Rs.16755.2). Thus application of Spinetoram 11.7% SC, Chlorantraniliprole 18.5% SC and Emamectin benzoate 5% SG proved to be the best bio-rational insecticides, regarding the management of fall armyworm and grain yield. (Table 4.28)

Table 4.28: Economics of various insecticides for the management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith)

Treatment	Insecticides	Grain yield (q/ha)	Increased yield over control (q/ha)	Price of increased yield over control	Cost of treatment (Rs/ha)	Net profit (Rs/ha)	Cost Benefit ratio
T1	Spinetoram 11.7% SC	35.41	12.75	22440	3750	18690	1 :4.98
T2	Chlorantraniliprole 18.5 % SC	34.31	11.65	20504	4600	15904	1 :3.45
T3	Emamectin benzoate 5% SG	32.18	9.52	16755.2	6250	10505.2	1 :1.68
T4	Pyriproxifen 10% EC	30.50	7.84	13798.4	4986	8812.4	1 :1.76
T5	*Beaveria bassiana*	28.10	5.44	9574.4	4550	5024.4	1 :1.10
T6	Azadirachtin 0.15% EC	31.01	8.35	14696	6650	8046	1 :1.20
T7	Buprofezin 25% SC	31.28	8.62	15171.2	4690	10481.2	1 :2.23
T8	*Bacillus thuringiensis*	28.50	5.82	10243.2	2963	7280.2	1 :2.45
T9	Control	22.66	-	-	-	-	

Labour cost = 3 labour/ha@ Rs. 250/ day

Total labour cost/ha (Two spray) = 2250 Rs.

Price of maize = 1760 Rs/quintal

Cost of treatment = Cost of labour + Cost of insecticide.

CHAPTER- V
SUMARRY AND CONCLUSION

Investigation on **"Biology and behavioural studies of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera : Noctuidae) along with its biorational management on kharif maize crop"** was carried out during kharif 2019-20 at the Research Cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G) and the main conclusions are summarized below –

5.1 *In vitro* studies on the biology and behaviour of fall armyworm on maize crop.

5.1.1 Biology of fall armyworm on different genotypes of maize crop

The female moths of *Spodoptera frugiperda* laid the eggs in masses on upper or lower surface of leaves. The length of eggs ranged from 0.39 to 0.53 mm with an average of 0.45 ± 0.01 mm, 0.38 to 0.60 with an average of 0.48 ± 0.08 mm, 0.39 to 0.59 mm with an average of 0.46 ± 0.07 mm, when the insect reared in fodder corn, sweet corn and hybrid corn, respectively. The incubation period was varied from 1 to 2 days with an average of 1.90 ± 0.10 days, 2 days with an average of 2.00 ± 0.00 days and 2 to 3 days with an average of 2.90 ± 0.10 days, where the selected hosts were fodder corn, sweet corn and hybrid corn, respectively.

Larval stage passed through six instars. The length of first, second, third, fourth, fifth and sixth instar larvae was 1.20 ± 0.02, 2.56 ± 0.10, 5.86 ± 0.04, 9.74 ± 0.08, 16.07 ± 0.06 and 33.18 ± 0.25 mm, respectively, when the host was fodder corn. The length of first, second, third, fourth, fifth and sixth instar larvae was 1.31 ± 0.04, 3.08 ± 0.02, 6.21 ± 0.07, 10.08 ± 0.06, 16.42 ± 0.12 and 33.47 ± 0.20 mm respectively, when the host was sweet corn. The length of first, second, third, fourth, fifth and sixth instar larvae was 1.37 ± 0.05, 3.11 ± 0.07, 5.92 ± 0.14, 9.97 ± 0.12, 16.01 ± 0.14 and 32.19 ± 0.25 mm, respectively. The width of head capsule of respective instars was 0.34 ±0.003, 0.43 ± 0.003, 0.74 ± 0.003, 1.29 ± 0.003 and 1.99 ± 0.003 mm, respectively, when the insect was reared in fodder corn. In sweet corn the head capsule width was recorded as 0.36 ± 0.003, 0.46 ± 0.003, 0.76 ± 0.003, 1.31 ± 0.003 and 2.01 ± 0.003 mm for respective instars, while in fodder corn the width of head capsule was recorded as 0.36 ± 0.003, 0.46 ± 0.003, 0.76 ± 0.003, 1.31 ± 0.003 and 2.01 ± 0.003 mm, respectively. The total larval period was observed as, 16.25 ± 0.17, 16.65 ± 0.16 and 20.25 ± 0.29 days, when the hosts were fodder corn, sweet corn and hybrid corn, respectively.

After the complete development of larvae, pre-pupal phase was initiated and this phase was marked by ceasing of feeding in larvae. The length and breadth of pre-pupae was observed as 20.0 ± 0.11 mm and 3.08 ± 0.02 mm, respectively, when the host was fodder corn. In case of sweet corn the length and breadth was noted as, 20.9 ± 0.27 mm and 3.11 ± 0.04 mm, respectively. The length and breadth was observed as 21.0 ± 0.37 mm and 2.64 ± 0.07 mm, when hybrid corn was selected as host of *S. frugiperda*. The duration of pre-pupal phase was 1.95 ± 0.05, 2.10 ± 0.06 and 2.95 ± 0.05 days, when the insect was reared in fodder corn, sweet corn and hybrid corn, respectively.

Pupae were soft and greenish to light brown in colour at starting but later on they turned into shiny reddish brown in colour. When the insect was reared in fodder corn, the length and breadth of the pupae were 14.3 ±0.23 mm and 4.22 ±0.07 mm, respectively but when the host was sweet corn, the length and breadth were 14.7 ± 0.31 mm and 4.22 ± 0.07 mm, respectively. In case of hybrid corn the length and breadth was observed 15.2 ± 0.23 mm and 4.16 ± 0.07 mm, respectively. Pupal period was 6.65 ± 0.22, 6.30 ± 0.14 and 6.95 ± 0.15 days, when the *S. frugiperda* was reared in fodder corn, sweet corn and hybrid corn, respectively.

The male and female adult moths were pale brown in colour but the forewings of female were less conspicuous. The size of female moth was slightly bigger than the male once. The length of male and female moth was observed 13.85 ± 0.20 and 19.00 ± 0.32 mm, respectively in fodder corn, 13.55 ± 0.32 and 20.20 ± 1.72 mm, respectively in sweet corn, 12.20 ± 0.39 and 19.55 ± 0.35 mm, respectively in hybrid corn. The wingspan of female and male moth was 3.37 ± 0.03 and 3.24 ± 0.03 cm, respectively in fodder corn, 3.24 ± 0.03 and 3.19 ± 0.03 cm, respectively in sweet corn, while 3.37 ± 0.02 and 3.12 ± 0.02 cm, respectively in hybrid corn.

The pre-oviposition period was observed 3.10 ± 0.06, 3.05 ± 0.05 and 3.70 ± 0.10 days in fodder corn, sweet corn and hybrid corn, respectively. The oviposition period was observed as 2.00 ± 0.00, 1.85 ± 0.08 and 2.00 ± 0.00 days in fodder corn, sweet corn and hybrid corn. For the respective genotypes of maize, the post-oviposition period was observed as 4.30 ± 0.12, 4.00 ± 0.07 and 4.60 ± 0.13 days. Longevity of female moth was observed 9.15 ± 0.19, 9.05 ± 0.19 and

9.20 ± 0.22 days in fodder corn, sweet corn and hybrid corn, respectively, while the longevity of male moth was observed 6.20 ± 0.11, 6.15 ± 0.13 and 6.60 ± 0.13 days in respective genotypes.

The fecundity of female adult was 454.2 ± 2.73, 557.2 ± 2.81 and 393.3 ± 5.79, when the insect was reared in fodder corn, sweet corn and hybrid corn, respectively. The sex ratio (Male : Female) was 1 : 1.80, 1 : 1.20 and 1 : 1.50 in fodder corn, sweet corn and hybrid corn, respectively under laboratory condition. The total life span for male and female was 32.9 ± 0.82 and 35.9 ± 0.90 days, respectively in fodder corn, 33.1 ± 0.69 and 36.0 ± 0.75 days, respectively in sweet corn, while 40.3 ± 0.88 and 42.9 ± 0.97 days, respectively in hybrid corn.

5.1.2 Behaviour of *S. frugiperda* on maize crop

5.1.2.1 Ovipositional preference behaviour

The female moth of *S. frugiperda* mainly preferred upper and lower surface of leaf and whorl for their egg laying but the lower surface of leaves were preferred than any other sites of maize crop.

5.1.2.2 Neonate feeding preference behaviour

The neonates were more attracted to sweet corn and fodder corn, where hybrid corn was the least preferred food source. The order of preference of hosts was hybrid corn < fodder corn < sweet corn.

5.1.2.3 Larval dispersal behaviour

The neonate larvae were feeding in same position till 12 hrs after hatching. This duration is termed as pre- feeding movement phase. The larvae were started spreading randomly after pre-feeding phase and they were begins to move to the upper surface from the lower surface of leaves. Young caterpillars were noted to spin through silken threads, by which they were able to move to the new plants. By the second and third instar, the larvae were completely separate. The later instars were move permanently into whorl.

5.1.2.4 Cannibalism behaviour

The frequency of cannibalism increased with diminishing food quantity. Cannibalism percent was found 66.6 ± 0.00 percent, when three larvae of fourth, fifth and sixth instar, respectively were examined. When two larvae of fifth and sixth instar were noticed the cannibalism percent was observed as 55.0 ± 4.50 percent. When two larvae of same age of sixth instar were examined the cannibalism percent was found 50.0 ± 0.00 percent. So, the rate of cannibalism of sixth instar larvae was greater, when the potential victim were younger than when the larvae were of same age.

5.1.2.5 Mating behaviour

The experiment resulted that the mating occurred throughout the 24 h cycle but majority of copulation started with evening hours and completed with night at between 6:00 pm to 10:00 pm. The duration of copulation was varied from 42 to 73 min with an average of 57.60 ± 3.49 min. Most mating (70%) lasted longer than 50 min. It was also observed that if the mating lasted longer, the percent of fertile eggs was higher.

4.3 Studies on parasitoids of different stages of fall armyworm in laboratory conditions.

During the entire period of study, total ten parasitoids (viz. *Chelonus sp., Cotesia sp., Bracon sp., Meteorus sp., Ischiodon scutellaris,* Unidentified sp. of Tachinid fly, *Buquetia musca, Helophilus sp., Phaonia sp.,* Unidentified species) of different stages of *S. frugiperda* were observed. Among ten parasitoids, one egg parasitoid, one egg larval parasitoid, seven larval parasitoids and one pupal parasitoid were observed on fall armyworm. All the parasitoids either belong to the order diptera or hymenoptera.

4.3 Relative efficacy of different bio-rational insecticides against fall army worm on maize crop.

The study of efficacy of different bio- rational insecticides against fall armyworm, *Spodoptera frugiperda* under field conditions was conducted in Randomize Block Design (RBD). According to the results of investigation, the larval percent reduction of fall armyworm was maximum in Spinetoram 11.7% SC @ 0.3 ml/l with 79.48 percent after first spray ,85.78 percent after second spray and 46.74 percent, which was followed by Chlorantraniliprole 18.5% SC @3.0 ml/l after first spray having 56.89 percent, 58.65 percent with second spray and 39.08 percent with third spray.

Similarly overall mean population of *S. frugiperda* was recorded minimum in Spinetoram 11.7% SC having 4.33 after first spray, 3.10 after second spray and 1.39 after third spray, larvae per five plants, which was most effective and followed by Chlorantraniliprole 18.5% SC having

9.10 larvae per five plants after first spray, 9.0 larvae per five plants after second spray while 1.59 larvae per five plants after third spray.

Price of increased yield over control was calculated and the highest price was of Spinetoram 11.7% SC (RS.22440) and lowest price was of *Beaveria bassiana* (Rs. 9574.4). The highest cost: benefit ratio was recorded with Spinetoram 11.7% SC (1: 4.98), while the lowest ratio was with *Beaveria bassiana* (1: 1.10). Thus application of Spinetoram 11.7% SC and Chlorantraniliprole 18.5% SC proved to be the best two bio-rational insecticides regarding management of fall armyworm.

Conclusion

1. The average life cycle of *Spodoptera frugiperda* took 34.4 ± 0.86 days in fodder corn, 34.5 ± 0.72 days in sweet corn and 41.6 ± 0.92 days in hybrid corn, in laboratory condition. There were six larval instars and the duration of larval stage was noted as 16.25 ± 0.17, 16.65 ± 0.16 and 20.25 ± 0.29 days in fodder corn, sweet corn and hybrid corn, respectively. The eggs were laid in cluster and covered by whitish scales. The duration of pupation period was observed 6.65 ± 0.22, 6.30 ± 0.14 and 6.95 ± 0.15 days in fodder corn, sweet corn and hybrid corn, respectively. Longevity of adult female was observed as 9.15 ± 0.19, 9.05 ± 0.19 and 9.20 ± 0.22 days, while the longevity of adult male was noted 6.20 ± 0.11, 6.15 ± 0.13 and 6.60 ± 0.13 days in fodder corn, sweet corn and hybrid corn, respectively.
2. In the group of ten parasitoids of *S. frugiperda*, larval parasitoids are in more numbers than other stage parasitoids. Among them *Cotesia sp.* (Hymenoptera: Braconidae) are more in numbers and observed in maize field from second week of sowing up to maturity of the crop.
3. Finally the economics of each insecticide was calculated to determine the best insecticide for management for the *Spodoptera frugiperda* in maize crop. The maximum net profit over control was found with Spinetoram 11.75 SC (RS. 18690) and the maximum benefit cost ratio (1: 4.98) was also recorded with same insecticide, whereas the minimum net profit (RS. 5024.4) was found with *Beaveria bassiana* and the minimum benefit cost ratio (1: 1.10) was recorded with same insecticide.

Suggestions for future research work

1. The investigations should be repeated to confirm the present results.
2. Efficient predators and parasitoids should be identified and utilized for the management of *Spodoptera frugiperda* in maize crop.
3. Suitable Integrated Pest Management strategies are needed to be applied for the management of *S. frugiperda*.
4. Studies on the pheromones of *S. frugiperda* should be conducted.
5. Efficacy of botanical insecticides against *S. frugiperda* should be studied.

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Appendix-I: Weekly meteorological data during crop growth period (from 16/07/2019 to 28/10/2019).

SMW	Month	Date	Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Wind velocity (Km/h)	Sunshine (hrs)
			Max	Min		I	II		
29	July	16-22	35.6	26.5	3.8	83.5	54.7	3.1	7.5
30		23-29	32.2	25.5	1.2	87.5	76.8	6.3	2.7
31		30-05	36.5	24.4	14.1	89.7	81.6	10.9	0.4
32	Aug	06-12	30.1	25.3	26.5	89.4	89.9	18.2	2.9
33		13-19	30.7	25.4	7.1	90.1	74.4	6.9	3.8
34		20-26	31.6	25.1	4.1	92.0	74.9	5.2	3.2
35		27-02	30.9	25.1	7.6	92.3	73.3	4.5	1.3
36	Sep	03-09	29.5	24.9	34.1	93.7	86.9	5.9	0.5
37		10-16	30.7	25	1.3	91.6	73.9	7.7	4.3
38		17-23	33.0	25.5	0.3	88.4	62.7	3.5	8.2
39		24-30	30.2	24.2	25.4	91.3	73.6	4.5	3.8
40	Oct	10-07	31.9	20.8	0.2	90.3	64.3	3.8	7.5
41		08-14	31.3	23.6	0.2	91.4	63.7	4.1	5.4
42		15-21	30.8	21.8	7.3	91.9	64.7	2.5	5.7
43		22-28	28.1	22.2	3.9	92.3	71.3	3.7	2.8

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