"BIOLOGY AND ECOFRIENDLY MANAGEMENT OF MUSTARD SAWFLY, *Athalia lugens proxima* (Klug) ON HALIV, *Lepidium sativum*"

By

Mr. Thigale Pravin Sadashiv
(Reg. No. 019/148)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413 722, DIST. AHMEDNAGAR
MAHARASHTRA, INDIA

in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL ENTOMOLOGY

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
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APPROVED BY

Prof. B.Y. Pawar
(Chairman and Research Guide)

Dr. G.B. Kabre
(Committee Member)

Dr. P.R. Palande
(Committee Member)

Dr. R.T. Gaikwad
(Committee Member)

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413 722, DIST. - AHMEDNAGAR
MAHARASHTRA, INDIA.
2021

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institution
for a Degree or
Diploma

Place : MPKV, Rahuri

Date : / /2021 **(P.S. Thigale)**

Prof. B.Y. Pawar
Assistant Professor,
AICRP on MAP & B,
Department of Agricultural Entomology,
Mahatma Phule Krishi Vidyapeeth,
Rahuri – 413 722, Dist. Ahmednagar
Maharashtra State, INDIA

CERTIFICATE

This is to certify that the thesis entitled, "**BIOLOGY AND ECOFRIENDLY MANAGEMENT OF MUSTARD SAWFLY, *Athalia lugens proxima* (Klug) ON HALIV, *Lepidium sativum*"** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri Dist. Ahmednagar (M.S.) in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRICULTURAL ENTOMOLOGY,** embodies the results of a piece of *bona fide* research work carried out by **Mr. THIGALE PRAVIN SADASHIV,** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

Place : MPKV, Rahuri (B.Y. Pawar)
Date : / /2021 Research Guide

Dr. C.S. Patil
Head,
Department of Agricultural Entomology,
Mahatma Phule Krishi Vidyapeeth,
Rahuri-413 722, Dist. Ahmednagar,
Maharashtra State, INDIA

CERTIFICATE

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Place : MPKV, Rahuri

Date : / /2021 (C.S. Patil)

Dr. P.N. Rasal
Associate Dean,
Post Graduate Institute,
Mahatma Phule Krishi Vidyapeeth,
Rahuri-413 722, Dist. Ahmednagar,
Maharashtra State, INDIA

CERTIFICATE

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Place : MPKV, Rahuri

Date : / /2021 (P.N. Rasal)

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Place : MPKV, Rahuri

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CONTENTS

Chapter No.	Title	Page No.
	CANDIDATE'S DECLARATION	**iii**
	CERTIFICATE OF RESEARCH GUIDE	**iv**
	CERTIFICATE OF HEAD OF THE DEPARTMENT	**v**
	CERTIFICATE OF ASSOCIATE DEAN	**vi**
	ACKNOWLEDGEMENT	**vii**
	CONTENTS	**ix**
	LIST OF TABLES	**xii**
	LIST OF FIGURES	**xiii**
	LIST OF PLATES	**xiv**
	LIST OF ABBREVIATIONS	**xv**
	ABSTRACT	**xvii**
1.	**INTRODUCTION**	1
2.	**REVIEW OF LITERATURE**	4
	2.1 Biology of Mustard Sawfly, *Athalia lugens proxima* (Klug)	4
	2.1.1 Eggs, Hatchability and Incubation Period	4
	2.1.2 Larval Period	5
	2.1.3 Pre-pupae, Pupae and Pupal Period	6
	2.1.4 Adult Longevity	7
	2.1.5 Life Cycle and Sex Ratio	7
	2.1.6 Pre-oviposition, Oviposition Period, Mating and Fecundity	8
	2.2 Management of Mustard Sawfly, *Athalia lugens proxima* (Klug)	8
3.	**MATERIALS AND METHODS**	13
	3.1 Place of Research Work	13
	3.2 Geographical Area	13
	3.3 Soil	13
	3.4 Climate	13

	3.5 Materials	14
	3.5.1 Seeds	14
	3.5.2 Rearing Materials	14
	3.5.3 Pesticides	14
	3.5.4 Appliances	14
	3.6 Methods	14
	3.6.1 Biology of Mustard Sawfly, *Athalia lugens proxima* (Klug)	14
	3.6.1.1 Rearing of test insect	14
	3.6.1.2 Method of recording observations	15
	3.6.2 To Study the Bioefficacy of Plant Products and Bio-pesticides Against Mustard Sawfly on Haliv, *Lepidium sativum*	16
	3.6.2.1 Details of experiment	16
	3.6.2.2 Method of applications of biopesticides and plant products	17
	3.6.2.3 Methods of recording observations	17
	3.6.2.4 Incremental cost benefit ratio and B:C ratio	18
4	**RESULTS AND DISCUSSION**	19
	4.1 Biology of Mustard Sawfly, *Athalia lugens proxima* (Klug)	19
	4.1.1 Egg Stage	19
	4.1.2 Larval Stage	19
	4.1.2.1 First instar	20
	4.1.2.2 Second instar	20
	4.1.2.3 Third instar	20
	4.1.2.4 Fourth instar	21
	4.1.2.5 Fifth instar	21
	4.1.2.6 Sixth instar	21
	4.1.2.7 Total larval period	22
	4.1.3 Pupal Stage	22
	4.1.4 Adult Stage	22
	4.1.5 Pre-oviposition Period	23
	4.1.6 Oviposition Period	23
	4.1.7 Post-oviposition Period	23
	4.1.8 Longevity of Adults	23

	4.1.9 Fecundity	24
	4.1.10 Hatchability	25
	4.1.11 Sex Ratio	25
	4.1.12 Egg to adult emergence	25
	4.1.13 Total Life Span	25
	4.2 Bioefficacy of Biopesticides and Plant Products Against Mustard Sawfly	26
	4.2.1 First Spray	26
	4.2.1.1 At 1 day before spray (pre-treatment count)	26
	4.2.1.2 At 3 days after spraying	26
	4.2.1.3 At 7 days after spraying	26
	4.2.1.4 At 14 days after spraying	27
	4.2.2 Second Spray	28
	4.2.2.1 At 3 days after spraying	28
	4.2.2.2 At 7 days after spraying	28
	4.2.2.3 At 14 days after spraying	29
	4.2.3 Cumulative Effect of Biopesticides and Plant Products Against Mustard Sawfly	30
	4.2.3.1 At 3 days after spraying	30
	4.2.3.2 At 7 days after spraying	31
	4.2.3.3 At 14 days after spraying	31
	4.3 Effect of Different Biopesticides and Plant Products Against Mustard Sawfly on Seed Yield of Haliv	32
	4.4 Incremental Cost Benefit Ratio (ICBR) and B:C Ratio of Different Biopesticides and Plant Products Against Mustard sawfly	33
5	**SUMMARY AND CONCLUSIONS**	36
	5.1 Summary	36
	5.1.1 Biology of Mustard Sawfly	36
	5.1.2 Bioefficacy of Biopesticides and Plant Products Against Mustard Sawfly	37
	5.1.3 Effect of Different Biopesticides and Plant Products Against Mustard Sawfly on Seed Yield of Haliv	37
	5.1.4 Incremental Cost Benefit Ratio (ICBR) and B:C Ratio of Different Biopesticides and Plant Products Against Mustard sawfly	38
	5.2 Conclusions	38
6	**LITERATURE CITED**	40
7	**VITAE**	46

LIST OF TABLES

Table No.	Title	Page
3.1	Treatment details for field trial on Haliv, *Lepidium sativum*	17
4.1	Developmental period of different life stages of mustard sawfly, *Athalia lugens proxima* (Klug) on *Lepidium sativum*	24
4.2	Measurements of different life stages of mustard sawfly, *Athalia lugens proxima* (Klug) on *Lepidium sativum*	25
4.3	Management of mustard sawfly, *Athalia lugens proxima* (Klug) after first spray on *Lepidium sativum*	27
4.4	Management of mustard sawfly, *Athalia lugens proxima* (Klug) after second spray on *Lepidium sativum*	29
4.5	Cumulative effect of biopesticides and plant products against mustard sawfly on *Lepidium sativum*	30
4.6	Effect of different biopesticides and plant products against mustard sawfly on seed yield of Haliv, *Lepidium sativum*	33
4.7	Incremental cost benefit ratio (ICBR) and B:C ratio of different biopesticides and plant products against mustard sawfly on *Lepidium sativum*	34

LIST OF FIGURES

Figures No.	Title	Between pages
3.1	Plan of experimental layout	16-17
4.1	Efficacy of biopesticides and plant products against mustard sawfly after first spray on *Lepidium sativum*	28-29
4.2	Efficacy of biopesticides and plant products against mustard sawfly after second spray on *Lepidium sativum*	30-31
4.3	Cumulative effect of biopesticides and plant products against mustard sawfly on *Lepidium sativum*	32-33
4.4	Effect of different biopesticides and plant products against mustard sawfly on seed yield of Haliv, *Lepidium sativum*	34-35

LIST OF PLATES

Plate No.	Title	Between pages
3.1	Field view experiment of Haliv, *Lepidium sativum*	14-15
3.2	Experimental setup for rearing of mustard sawfly in the laboratory	14-15
4.1	Different larval instars of mustard sawfly, *Athalia lugens proxima* (Klug)	20-21
4.2	Adults of mustard sawfly, *Athalia lugens proxima* (Klug)	22-23
4.3	Oviposition and mating in mustard sawfly	24-25
4.4	Life cycle of mustard sawfly, *Athalia lugens proxima* (Klug)	24-25
4.5	Spraying of plant products and biopesticides against mustard sawfly on Haliv, *Lepidium sativum*	26-27

LIST OF ABBREVIATIONS AND SYMBOLS

@	:	At the rate of
/	:	Per
%	:	Per cent
+, -	:	Plus, Minus
^{0}C	:	Degree Celsius
>	:	Greater than
Av.	:	Average
B:C	:	Benefit Cost Ratio
Bt	:	*Bacillus thuringiensis*
CD	:	Critical difference
cm	:	Centimetre
DAS	:	Days after spraying
DMAPR		Directorate of Medicinal and Aromatic Plants Reseach
EC	:	Emulsifiable Concentrate
e. g.	:	Exempli gratia, For example
et al.	:	Etalia and others
etc.	:	Etcetera
Fig	:	Figure
g	:	Gram (s)
ha	:	Hectare (s)
hr	:	Hour (s)
ICAR	:	Indian Council of Agricultural Research
ICBR	:	Incremental Cost Benefit Ratio
i.e.	:	idest, that is
kg	:	Kilogram (s)
L, lit.	:	Litre (s)
M	:	Meter
mg	:	Milligram (s)
ml	:	Milliliter (s)
mm	:	Millimeter (s)
MPKV	:	Mahatma Phule Krishi Vidyapeeth
NHB	:	National Horticulture Board
No.	:	Number

NS	:	Non-significant
PTC	:	Pre-treatment Count
q/ha	:	Quintals per Hectare
RBD	:	Randomized Block Design
RH	:	Relative Humidity
Rs.	:	Rupees
S.E.	:	Standard Error
SG	:	Soluble Granules
spp.	:	Species
Tr. No.	:	Treatment Number
Var.	:	Variety
viz.,	:	Uidelicet (Namely)
WP	:	Wettable Powder

ABSTRACT

"BIOLOGY AND ECOFRIENDLY MANAGEMENT OF MUSTARD SAWFLY, *Athalia lugens proxima* (Klug) ON HALIV, *Lepidium sativum*"

By

Mr. THIGALE PRAVIN SADASHIV

A candidate for the degree
of
MASTER OF SCIENCE (AGRICULTURE)
in
AGRICULTURAL ENTOMOLOGY

Mahatma Phule Krishi Vidyapeeth, Rahuri - 413 722
2021

Research Guide	**:**	**Prof. B.Y. Pawar**
Department	**:**	**Agricultural Entomology**

The mustard sawfly, *Athalia lugens proxima* (Klug) (Hymenoptera: Tenthredinidae) is a major pest of Haliv in India. The biology and morphometric parameters of mustard sawfly were studied at Post Graduate Laboratory, Department of Agricultural Entomology, M.P.K.V., Rahuri during *rabi* 2020-21 and the research work on management of mustard sawfly was conducted during *rabi* 2020-21 at the farm of AICRP on MAP and B, M.P.K.V., Rahuri. The experiment was laid out in randomized block design (RBD) with three replications and seven treatments with view to evaluate plant products and biopesticides against mustard sawfly.

The female adult fly of *Athalia lugens proxima* (Klug) laid eggs singly, in slits made with saw like ovipositor along the under sides of the leaf margin. The incubation period varied to vary from 6 to 8 days with mean incubation period of 6.95 ± 0.69 days. The mean larval and pupal period was 12.65 ± 1.95 and 12.25 ± 1.37 days, respectively. Males lived longer than females. The average life span of male and female mustard sawfly was observed as 45.35 ± 6.45 and 41.60 ± 5.69 days, respectively. Male adult of sawfly was more active and smaller than female. It had black head. Prothorax was orange in colour and pterothorax was black in colour.

Abstract contd…. **Mr. Pravin S. Thigale**

Two pairs of wings were smoky with black veins. Abdomen was orange coloured. Larvae shown feign death on touching.

Among all treatments, *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water spray showed to be the significantly superior treatment which recorded 1.93 mustard sawfly larvae per plant and at par with the treatment, *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water spray (2.10 mustard sawfly larvae per plant).

From the data on percent reduction in mustard sawfly larval population over pre count after two sprays, the different treatments are listed in descending order for reducing larval population as *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water (67.98), *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (64.15), *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (59.82), Azadirachtin 10000 ppm @ 2 ml/lit. water (56.43), Karanj oil @ 2 ml/lit. water (34.63) and NSE 5 % @ 50 g/lit. water (26.68).

The highest Haliv seed yield (17.49 q/ha) was recorded from the treatment, *Bt* spray (*Bacillus thuringiensis* @ 2 ml/lit. of water) and it was followed by *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water spray (16.18 q/ha).

Among all treatments, the highest incremental cost benefit ratio of 1:9.96 was recorded by *Beauveria bassiana* 1.15 % WP @ 5g/lit. water spray, followed by *Bt* spray (*Bacillus thuringiensis* @ 2ml/lit. of water) with 1:8.85 incremental cost benefit ratio. The highest B:C ratio 1:2.26 was recorded by *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water spray), followed by *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water with of 1:2.14 B:C ratio.

Pages 1 to 46

1. INTRODUCTION

India's diverse agro climatic condition and topography have large number of medicinal plant species. The herbal wealth is about 5000 species known aromatic and medicinal plants used in different systems of Indian medicine like Siddha, Unani and Ayurveda.

Haliv (*Lepidium sativum*) is an annual edible herb belonging to family Brassicaceae. It is known as ‘pepper cress’ or ‘water cress’ or ‘garden cress’. Its common names include Halim (Sanskrit); Common Cress (English); Aseliyo (Gujrati); Chandrashoor (Hindi); Kapila (Kannada); Alian (Kashmiri); Asali (Malayalam); Chandasura (Oriya); Haliv (Marathi); Allivirai (Tamil); Aadalu (Telugu) and Halim (Urdu).

It is native to West Asia and Europe (Gokavi *et al*., 2004). It is an important medicinal plant from India. In India, its cultivation spread across the states of Maharashtra, Gujarat, Uttar Pradesh, Madhya Pradesh and Rajasthan in an area about 5000 hectares (Choudhary *et al*., 2010). It is grown in India in the states like Uttar Pradesh, Tamil Nadu, Madhya Pradesh, Maharashtra and Rajasthan for seeds (Gokavi *et al.,* 2004). Haliv is an important medicinal crop grown it the winter season in the Malwa plateau (Tiwari and Kulmi, 2004). Seeds, leaves and roots are economically and medicinally important. In India, entire area under garden cress is 8450 ha (Anon., 2014).

Plants are 45 to 60 cm tall. Its leaves are pinnatisect, entire or variously lobbed. Flowers are white and tiny, arranged in racemes. The seeds have laxative and diuretic properties. The seed’s mucilage is used to treat intestinal irritations. Leaves are useful for treatment of liver diseases. Salad which made from leaves used to cure anaemia. Propagation is done through seeds (Anon., 2019, DMAPR, Anand).

The seeds morphologically resemble to some of the oil seeds with the dicotyledonous endosperm contributing 80 to 85 per cent seed matter. Embryo and seed coat account for 2 to 3 per cent and 12 to 17 per cent of seeds, respectively. The endosperm has yellow colour. The seed coat is brick red to cream coloured. The seed contains alkaloid like lipidin, glucotropaeolin, mucilaginous matter (5 %), sinapinic acid and uric acid (0.108 g/kg). Seeds also contain B vitamins and vitamin C. The seeds yield

yellowish brown semi drying oil having somewhat disagreeable odour. The composition of seed is as moisture (5.69 %), protein (23.50 %), fat (23.5 %), ash (5.7 %), sulphur (0.9 %), phosphorous (1.65 %) and calcium (0.31 %) (Wadhwa *et al*., 2012).

Garden cress leaves are having composition of water (82.3 %), protein (5.8 %), fat (1.0 %), carbohydrates (8.7 %), calcium (0.36 %), phosphorous (0.11 %) and trace elements *viz*., Iron (28.6 mg/100 g), cobalt (12 µg/kg), iodine (110 µg/kg), nickel (40 µg/kg), vitamin C (39 mg/100 g), vitamin A (30300 IU) and riboflavin (0.15 mg). Leaves of garden cress claim to possess diuretic, aperients and aphrodisiac activity and recommended for treatments of inflammation, chest complaints, bronchitis, rheumatism and muscular pain. It is reported to improve brain power and brightening of intellect (Kirtikar and Basu, 1933).

In folk medicine, *L. sativum* is used as a therapy for inflammatory diseases including *Diabetes mellitus*, arthritis and hepatitis (Bigoniya and Shukla, 2014; Sakran *et al*., 2014). The extract of *L. sativum* possesses antioxidant, antidiarrheal, antimicrobial, anti-inflammatory and hepatoprotective effects against oxidative damage (Doke and Guha, 2014; Al-Sheddi *et al*., 2016; Raish *et al*., 2016). It is used in preparation of medicines for asthma, cough, leprosy, skin disease, dysentery, diarrhoea, splenomegaly, dyspepsia, lumbago, leucorrhoea, scurvy and seminal weakness (Kirtikar and Basu, 1933). Seeds are used for recovery of chronic bronchial asthma and enhancing milk yield in both animals and human beings.

Athalia lugens proxima (Klug) (Hymenoptera: Tenthredinidae) commonly known as mustard sawfly is a major pest of mustard (Sharma *et al.,* 1992). It is one of the very few hymenopteran insects found as crop pests. The mustard sawfly is widely distributed in Indonesia, Formosa, Burma and the Indian subcontinent. Mustard sawfly recorded first time from the Bombay and Bengal state (Middleton, 1894). The pest incidence has been observed from almost all the states of India. Mustard sawfly, *Athalia lugens proxima* (Klug) (Hymenoptera: Tenthredinidae) had became a serious pest of cruciferous crop in oriental region (Patil and Pokharkar, 1973; Patel and Jhala, 1999; Yadav and Patel, 2017).

Mustard sawfly causes damage to mustard, cauliflower, radish, cabbage, knol-khol. It is reported on garden cress (*Lepidium sativum*) (Anon., 2012-2013,

DMAPR, Anand). It is a polyphagous insect and considered as devastating pest of vegetables. This pest generally active during October to March. The host range of this pest includes 14 plant species belonging to Cruciferae and *Tropaeolum majus* (Sehgal and Ujagir, 1977). Mustard is the preferred host for feeding and oviposition (Bindra and Mehra, 1964; Singh and Sachan, 1998). The larvae infest the young leaves followed by skeletonization of leaves. It also feeds on the epidermis of the tender shoots, fruits and flowers (Chowdhury, 2009). Female causes indirect damage by injuring leaf tissue while inserting the eggs with her ovipositor. The pest attack causes severe defoliation resulting in huge loss in seed yield due to death of plants during early stages and sometimes resowing becomes necessary (Jagtap and Kadam, 1978).

Excess use of pesticides causes residue problems as well as soil pollution. Keeping this in view, research was undertaken on the "Biology and ecofriendly management of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv*, Lepidium sativum*" during *rabi*, 2020-21 by using bio-pesticides and plant products with following objectives –

1. To study the biology of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv, *Lepidium sativum.*
2. To study the bioefficacy of plant products and bio-pesticides against mustard sawfly on Haliv, *Lepidium sativum.*

2. REVIEW OF LITERATURE

The mustard sawfly is the major pest on Haliv, *Lepidium sativum*. It causes 36.89 per cent seed yield loss in *Lepidium sativum.* The literature on biology and ecofriendly management of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv*, Lepidium sativum* is not available. Thus, the available literature is presented below.

2.1 Biology of Mustard Sawfly, *Athalia lugens proxima* (Klug)

The biology of *Athalia lugens proxima* (Klug) had been studied by many scientists and reviewed as given below.

2.1.1 Eggs, Hatchability and Incubation Period

Tripathi (1963) studied on biology of mustard sawfly, *Athalia lugens proxima* (Klug) and found incubation time was 6 to 8 days.

Shirke *et al*. (1968) found that freshly laid eggs on radish were oblong, greenish and sized 0.66 x 0.35 mm and they also studied hatchability of eggs was found to be 80.1 to 91 per cent.

Patil and Pokharkar (1973) studied on bionomics and control of mustard sawfly, *Athalia lugens proxima* (Klug) and noticed oval creamy white eggs with a length of 0.78 ± 0.12 mm and a width of 0.52 ± 0.15 mm.

Jagtap and Kadam (1978) investigated biology of mustard sawfly, *Athalia lugens proxima* (Klug) on radish crop and found the average width and length of eggs laid on radish as 0.35 and 0.65 mm, respectively.

Kapadia *et al.* (1980) recorded observations on biology and larval and post larval development of mustard sawfly, *Athalia lugens proxima* (Klug) on different host plants and found that incubation takes 6.21 days under the laboratory conditions.

Sumithramma *et al.* (1997) noticed oval, creamy and smooth freshly laid eggs on mustard that later changed into black colour with length ranging from 0.71 to 1.43 (1.00) mm and width ranging from 0.42 to 0.71 (0.53) mm.

Sahu *et al.* (2018) studied the life system of sawfly and recorded that the incubation period was 4 to 5 days. Eggs are inserted singly in slits made by saw-like ovipositor along the leaf margin of mustard and rapeseeds.

2.1.2 Larval Period

Bogawat (1967) studied on biology of mustard sawfly, *Athalia lugens proxima* (Klug) and reported that the larval period depends on host plants. The mean larval period on mustard was 12 days.

Patil and Pokharkar (1973) studied that the larvae had six instars in a time span of 13 to 15 days and observed the length of 1st instar was 2.19 mm and that of 6th instar was 13.72 mm. They also observed durationfor first instar (2.5 days), second instar (1.8 days), third instar (2.0 days), fourth instar (2.8 days), fifth instar (2.2 days) and sixth instar larva (1.8 days).

Jagtap and Kadam (1978) investigated biology of mustard sawfly, *Athalia lugens proxima* (Klug) on radish crop. They recorded that the larvae went through five moults and was 14.24 mm long when fully grown and 12.73 days larval period on radish from November to March, 1978.

Kapadia *et al*. (1980) studied the biology of *Athalia lugens proxima* on mustard and found that 1st and 2nd instar larvae had black head with greyish green body. The third to fifth instar larvae were black with colourful bands on dorsum, whereas the sixth instar larvae were black with five long strips on the dorsum. They recorded the average length of first instar (1.94 mm), second instar (3.52 mm), third instar (6.04 mm), fourth instar (9.24 mm), fifth instar (12.33 mm) and 6th instar (13.33 mm). Further noticed larval period of 14.66 days in the laboratory at 21-26°C temperature and larval duration of first instar larvae (1.25 days), second instar larvae (2.83 days), third instar larvae (3.25 days), fourth instar larvae (3.83 days), fifth instar larvae (1.92 days) and sixth instar larvae (1.83 days).

Abe (1988) conducted experiment on a biosystematics study of genus *Athalia leach* of Japan. He noticed that the male instars were five and female instars were six.

Singh and Sachan (1997) observed the effect of different temperatures and host plants on the developmental behaviour of mustard sawfly, *Athalia proxima*. The larval period of 13.7 days at 20 °C, 11.4 days at 25 °C and 12.4 days 30 °C.

Sumithramma *et al*. (1997) measured the average morphometrics of first, second, third, fourth, fifth and sixth instar larva reared on mustard were 2.03 mm x 0.37

mm, 3.78 mm x 0.71 mm, 5.20 mm x 1.02 mm, 7.81 mm x 1.40 mm, 11.62 mm x 2.06 mm and 12.45 mm x 2.34 mm, respectively. When larvae reared on mustard the duration of first instar, second instar, third instar, fourth instar, fifth instar and sixth instar were 2.70 ± 0.47, 1.55 ± 0.60, 1.85 ± 0.36, 1.85 ± 0.48, 2.90 ± 0.44, and 1.55 ± 0.51 days, respectively.

Babendreier and Polesny (1999) taken observations on the biology and phenology of *Athalia* spp. (Hymenoptera: Tenthredinidae) parasitizing the cocoons of the apple sawfly, *Hoplocampa testudinea* (Hymenoptera: Tenthredinidae) and observed that hibernation of mature larvae took place in the cocoon.

Sahu *et al.* (2018) studied the life span of sawfly and noticed larval period was 13 to 18 days. Larva was cylindrical, greenish black with wrinkled body and has 7 to 8 pairs of prolegs. A full grown larva length was 16 to 18 mm. It showed feign death behaviour when touched.

2.1.3 Pre-pupae, Pupae and Pupal Period

Dhillon (1966) studied morphology and biology of *Athalia proxima* (Tenthredinidae : Hymenoptera) and stated that the pupal stage lasted for 10 to 15 days.

Patil and Pokharkar (1973) studied on bionomics and control of mustard sawfly, *Athalia lugens proxima* (Klug) and observed the insect remained quiescent during pre-pupal stage. Prolegs gradually disappeared and the body length shrank noticeably.

Kapadia *et al*. (1980) noticed full grown larvae casted off exuviae and then penetrated into the soil to pupate in an earthen cocoon which pupal period lasted for 10 to 15 (12.79) days. The cocoon had a length of 6 to 8 (6.69) mm and a width of 3 to 4 (3.40) mm.

Verma and Sachan (1996) recorded effect of different moisture regimes and soil types on pupation behaviour of *Athalia proxima* and also noticed that the larvae required 15 per cent moisture to pupate mostly into the sandy soil.

Sumithramma *et al*. (1997) found exarate pupae and analysed the morphometrics (length x width) of pre-pupae and pupae reared on mustard which were found to be 10.32 mm x 2.08 mm and 7.53 mm x 3.05 mm, respectively.

Sahu *et al.* (2018) studied the life system of sawfly. Pupation took place in an earthen cocoon in the soil and the pupal duration was 10 to 15 days.

2.1.4 Adult Longevity

Bogawat (1967) studied on biology of mustard sawfly, *Athalia lugens proxima* (Klug) found that adult males survived 8.75 days on mustard, whereas females survived 11.00 days.

Jagtap and Kadam (1978) studied biology of mustard sawfly, *Athalia lugens proxima* (Klug) on radish crop. Morphometrics of adult male and female were recorded as 5.19 mm x 1.22 mm and 6.61 mm x 1.84 mm, respectively.

Kapadia *et al*. (1980) observed males survived more than that of females. Black and orange to yellow coloured adults had smoky wings with black veins. They also discovered that on an average female and male were 5.1 and 4.46 mm long, respectively. The wingspan of male observed to be 10.78 mm and that of female was 12.20 mm.

Abe (1988) conducted experiment on a biosystematics study of genus *Athalia leach* of Japan. Its female was 6.8 mm long while male was 6.3 mm long.

Sumithramma *et al*. (1997) recorded adult observations on mustard and measured the size of male (6.5 mm x 1.79 mm) and female (7.86 mm x 2.17 mm) noticed that female reared on mustard lived for 15.90 ± 2.60 days and adult male survived for 13.20 ± 3.32 days.

Babendreier and Polesny (1999) taken observations on the biology and phenology of *Athalia* spp. (Hymenoptera: Tenthredinidae) parasitizing the cocoons of the apple sawfly, *Hoplocampa testudinea* (Hymenoptera: Tenthredinidae) and observed that males of this species lived for 50 days while female survived significantly longer for 72 days under laboratory conditions in Switzerland.

2.1.5 Life Cycle and Sex Ratio

Jagtap and Kadam (1978) investigated biology of mustard sawfly, *Athalia lugens proxima* (Klug) on radish crop. During different seasons, the life cycle was completed in 29.9 days in *kharif* and 32.19 days in *rabi*. They also recorded a sex ratio of 1:2.6 (male adult: female adult).

Sumithramma *et al*. (1997) studied biology of mustard sawfly, *Athalia lugens proxima* Klug. (Hymenoptera: Tenthredinidae) on mustard and radish in South India. A period of 29.10 ± 1.15 days was required from egg to adult emergence.

Babendreier and Polesny (1999) observed the life history of *Athalia* spp. in laboratory and field experiments (Switzerland). Development from egg to adult was completed in 39 days for females and in 38 days for males.

2.1.6 Pre-oviposition, Oviposition Period, Mating and Fecundity

Bogawat (1967) studied on biology of mustard sawfly, *Athalia lugens proxima* (Klug) and recorded oviposition duration on mustard was 6.75 days.

Ahuja and Sehgal (1982) observed effect of seed extracts containing mustard oil flucosides on the biology of mustard sawfly, *Athalia proxima* (Klug) and found that the female released 77.70 ± 5.99 eggs over her lifetime under controlled conditions.

Sumithramma *et al.* (1997) discovered that mature males and females mated in an end-to-end position with a copulation act lasting 0.5 to 3 minutes and also noticed average pre-oviposition duration as 5.3 hours on mustard.

Sahu *et al.* (2018) studied the life system of sawfly. Mustard sawfly adult female laid eggs singly, in slits made with saw like ovipositor along the under sides of the leaf margin and each female laid 60 eggs.

2.2 Management of Mustard Sawfly, *Athalia lugens proxima* (Klug)

Pandey *et al*. (1977) showed that extracts of several plants had an antifeedant effect against larvae of mustard sawfly. The order of effectiveness was 0.05 per cent ether extract of rhizomes of *Acorus calamus* > 0.1 per cent *A. calamus*, followed by cent per cent leaf extract of *Euphorbia royleana* > 100 per cent *Lantana camara* extract > 50 per cent *E. royleana* > 100 per cent *Crinum bulbispermum* > 100 per cent *Aloe vera* > 50 per cent *C. bulbispermum* > 50 per cent *A. vera* > 50 per cent *L. camara*. *A. calamus* showed the strongest repellent effect, followed by undiluted extracts of *E. roylena, L. camara, C. bulbispermum* and *A. vera*. Out of all only *A. calamus* showed insecticidal effect.

Sudhakar *et al*. (1978) conducted an experiment to explore the antifeedant properties of ether extract of rhizomes of *A. calamus* and mechanical leaf extracts of *Crinum defixum*, *E. royleana*, *L. camara var. aculeata* and *Aloe barbadensis* against the mustard sawfly, *Athalia lugens proxima* and found that all extracts tested showed good

antifeedant property. However, the ether extract of rhizomes of *A. calamus* was highly effective.

Arunkumar *et al*. (1979) investigated that spraying of mustard crop with 2, 1 and 0.5 per cent bitter gourd seed oil resulted on an average of 8.27, 38.7 and 27.7 per cent mortality of mustard sawfly after 24 hr, respectively. No mortality found in control treatment.

Pandey *et al.* (1979) recorded the mean per cent reduction of mustard sawfly larval population in the extract of *A. calamus* at 12 hr after spraying. The 100 per cent mechanical extracts (undiluted) were effective when compared to 50 per cent (diluted) extracts.

Banergi *et al.* (1982) tested six plant extracts for their antifeedant effects against larvae of *Athalia lugens proxima* (Klug), when sprayed on raddish leaves provided as food, 0.5 per cent alcohol extract of *Derris indica* seeds, 2.5, 1.0 and 0.5 per cent petroleum ether extracts of *A*. *calamus* and 2.5 per cent alcohol extract of garlic resulted in 100 per cent protection of leaves.

Chari and Muralidharan (1985) recorded that neem kernel suspension at 2, 3 and 5 per cent concentrations as well as neem leaf suspensions at concentrations of five and ten per cent had antifeedant activity on fourth instar larvae of *Athalia lugens proxima* (Klug). They recommended that 2 per cent neem seed suspension or 10 per cent neem leaf extract would be an effective and cost effective treatment for *Athalia lugens proxima* control.

Johri *et al*. (1986) investigated that the effect of alkaloid extracts of *Delphinium ajacis, Datura metel var. aiba*, *Argimona mexicana* and *Ricinus communis* L. and a glucoside extract of *Thevetia neriifolia* at concentrations of 0.5, 1.0, 1.5, and 2 per cent against larvae of *Athalia lugens proxima (Klug)*. The extracts of 0.5 per cent of *D. ajacis, D. metel* and *T. neriifolia* produced 100 per cent mortality of *Athalia lugens proxima* (Klug) within 48, 60 and 72 hr, respectively.

Patnaik *et al.* (1987) studied that 3.0 per cent neem oil caused 100 per cent larval mortality of *A. proxima* whereas untreated check had no mortality of *A. proxima*. The sudden drop was detected at concentrations greater than 0.4 per cent.

Umeh (1988) recorded that high concentration (5 and 10 %) of extracts of neem seed kernel was highly repellent and phagodeterrent to 2nd and 4th instar larvae of *Athalia lugens proxima*. Only the high concentration remained completely effective for 48 hr, but in long run all the 2nd instar larvae that fed on treated leaves died. Concentrations of 0.1 and 10 per cent resulted in 90 and 10 per cent survival of fourth instar larvae of *A. proxima*.

Pawar and Thombare (1990) evaluated *Bacillus thuringiensis sub sp. Kurstaki* (Biobit) against 12 insect pests. Foliage contaminated with 0.0625 to 2.0 per cent Biobit given to starved *A. proxima* larvae of 2nd to 4th instar. LC_{50} of 0.145 per cent was obtained for third instar larvae of the *Athalia lugens proxima*.

Singh *et al*. (1993) tested some plant products to control mustard sawfly, *Athalia proxima* under field experiment with concentrations of 0.5, 1.0 and 1.5 per cent. Spray applications of *Azadirachta indica, Saussurea lappa* and *Lantana camera* was more effective for reduction of pest incidence and significantly yield was also higher in comparison to other extracts.

Sontakke and Dash (1994) studied that the efficacy of synthetic insecticides and neem formulations for the control of *L. erysimi* and *A. lugens proxima* on mustard. All chemicals reduced the incidence of *L. erysimi* and *A. lugens proxima* infesting mustard compared to control. Nimbecidine and Azadirachtin gave a comparatively better level of control for both the pests and a higher seed yield.

Dodia *et al*. (1995) noticed that the larvae of mustard sawfly*, A. lugens proxima* failed to damage the leaves when leaves treated with extracts of neem leaves at 10 per cent and neem seed kernel at 5 per cent. They also reported that the NSKE at 5 per cent was proved be very effective.

Srinivas Rao *et al.* (1996) studied that botanical pesticide from neem acted effective photodeterrents at 0.1 per cent concentrations but without causing significant mortality of *Athalia lugens proxima (Klug)* when compared to 0.005 per cent endosulfan. Sawfly larvae which fed on treated leaves underwent pupation but adults did not emerge.

Venkateshwarlu *et al*. (1998) recorded that repellent and antifeedant activity of neem oil at 8 and 16 per cent concentration against the larvae of *A. lugens proxima*. The percentage of antifeedant activity and repellency decreased with decreasing concentrations of neem.

Srivastava and Singh (2003) applied neem leaf powder at rate of 75 kg/ha in furrows of soil at sowing time and recorded reduction in population of mustard sawfly and the grain yield increased 5.2 per cent over control.

Hasan and Singh (2009) investigated that LC_{50} values of Halt (*Bacillus thuringiensis*), Biorin (*Beauveria bassiana*) and Nemarin (Azadirachtin) were evaluated at 24 hrs, 48 hrs, 72 hrs and 96 hrs after treatment against mustard sawfly. The LC_{50} values were 0.6574 per cent, 6.14 x 10^7 spores/ml and 0.0096 per cent obtained for Halt, Biorin and Nemarin, respectively at 24 hrs after treatment. In the second set of experiment, in which observations were taken at 48 hr after treatment, the LC_{50} values were obtained as 0.4692 per cent, 5.05 x10^7 and 0.0085 per cent for Halt experiment mortality count was made at 72 hrs after Biorin and Nemarin, respectively. While in the third set of treatment in which the LC_{50} values were calculated as 0.3831 per cent, 4.13 x10^7 and 0.0067 per cent for Halt, Biorin and Nemarin respectively. Likewise in the fourth set of experiment mortality count was made at 96 hrs after treatment and the LC_{50} values of Halt, Biorin and Nemarin were 0.2598 per cent, 3.53x10^7 and 0.0051 per cent, respectively.

Chandel *et al.* (2011) studied that extract of *Alpinia galanga* caused maximum larval mortality (80.8 %) of *Athalia proxima*, followed by 67.9 per cent in *C. longa*, 66.3 per cent in *A. melegueta* and 62.1 per cent in *Z. officinale* when compared to 6.6 per cent in control.

Yadav (2012) demonstrated that all the three indigenous strains of EPNs are virulent to *A. lugens proxima* larvae, however, *H. indica* and *S. thermophilum* show better efficacy than *S. glaseri.* Similarly, except *S. glaseri*, the other two EPN isolates also show good reproductive potentials in sawfly larvae. It is concluded that these EPN isolates have good potential as bio-control agents against mustard sawfly, *A. lugens proxima*.

Yadav and Patel (2017) studied that the leaves crude aqueous extracts of five plants *viz*., *Ageratum conyzoides* L*., Parthenium hysterophorus* L*., Lantana camera* L*., Solanum nigrum* L. and *Cannabis sativa* L. were investigated for their insecticidal property against larvae of *Spodoptera litura* (F.) and *Athalia lugens proxima* (Klug). The results revealed that the maximum mortality (93.33 %) of *Spodoptera litura* was obtained in 5 per cent concentration and at 96 hours exposure in the treatments of *Cannabis sativa* and *Solanum nigrum*. The larvae of *Athalia proxima* was found somewhat susceptible

compared to the larvae of *Spodoptera litura* and highest mortality of 93.33 per cent was recorded in 5 per cent concentration and at 72 hours exposure in the treatments of *Ageratum conyzoides* and *Solanum nigrum*. The mortality was directly related to concentration and exposure period. These five plants can be used as botanical insecticide to manage the insect problems.

Chandel and Sengar (2018) investigated that, among ten plant extract, only Azadiron (48.15) showed highest repellency, followed by NLE (34.77) and Neemarin (4.33) times repellent than NSKE (1.00) against larvae of *Athalia lugens proxima*. All the extracts tested were effective to some degree of repellence reducing the feeding and destruction rates.

Kalsaria and Parmar (2019) recorded 33.12 per cent mean mortality of mustard sawfly larvae caused by NSKE 5 per cent when applied on mustard at 50 per cent flowering. They also recorded 1:3.1 ICBR ratio with application of (*B. bassiana* 2.5 kg/ha + Acetamiprid 20 % SP+ Spinosad 45 % SC + cypermethrin 4 % EC) and (NSKE 5 % + Monocrotophos 36 % SL + Quinolphos 25 % EC + Ethion 40 + Cypermethrin 5 % EC) against mustard sawfly infesting mustard.

Pradhan *et al.* (2020) investigated that, in *Brassica campestris var. Toria* mustard sawfly population in different entomopathogenic fungus revealed that *L. lecanii* (NBAIR) was the superior treatment (0.29 sawfly/plant) compared to *L. lecanii* (AAU-J culture) (0.38 sawfly/plant) and *B. bassiana* (AAU-J culture) (0.48 sawfly/plant). The sawfly population reduction in the order of Dimethoate 30 EC > *L. lecanii* (NBAIR) > *L. lecanii* (AAU-J culture) > *B. bassiana* (AAU-J culture) > *M. anisopliae* (AAU-J culture) > Azadirachtin @ 2 ml/lit. The per cent reduction in mustard sawfly larval population over control caused by *Beauveria bassiana* @ 5g/lit. water was 67.11 per cent. The application of Azadirachtin 1500 ppm @ 2 ml/lit resulted in a 57.88 per cent reduction in mustard sawfly larval population compared to the control. The application of *Metarhizium anisopliae* @ 5 g/lit showed in a 61.48 per cent reduction in mustard sawfly larval population compared to the control. Further, they recorded B:C ratio against major insect pests of *Brassica campestris var. toria* as 1:2.25, 1:2.15 and 1:2.06 for treatments *Beauveria bassiana*, *Metarhizium anisopliae* and Azadirachtin, respectively.

3. MATERIALS AND METHODS

The investigation entitled "Biology and ecofriendly management of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv, *Lepidium sativum*" was studied in *rabi*, 2020-2021. The details of materials used and methodology adopted during the present investigation are described under this chapter.

3.1 Place of Research Work

During the years 2020-2021, the study was conducted at both in the field and in the lab. Field experiment was set at AICRP on Medicinal, Aromatic Plants and Betelvine, Mahatma Phule Krishi Vidyapeeth, Rahuri during *rabi,* 2020-2021 and laboratory experiment conducted at Post Graduate Laboratory, Department of Agricultural Entomology, Post Graduate Institute, M.P.K.V., Rahuri.

3.2 Geographical Area

Geographically, central campus of M.P.K.V., Rahuri is situated at $19^0$47' and $19^0$55', North latitude and $74^0$19' to $74^0$42' East longitude. Height of this place is 525 meter above the mean sea level. This track is lying on the eastern side of western ghat. It comes under rain shadow region.

3.3 Soil

The field was uniform and level. The soil of investigation area was light to medium black and moderately fertile. It also had adequate drainage.

3.4 Climate

This area is a water scarcity zone with an annual rainfall ranging from 317 to 619 mm. The average annual rainfall is 520 mm and the rainfall distribution is about 15 to 45 rainy days. About 80 per cent rainfall is received from South-West monsoon whereas rest is from North-East monsoon.

The average annual temperature is 32^0C and average minimum temperature is 17.60^0C. The mean relative humidity at 8.00 and 14.00 hr. is 72.82 and 37.52 per cent, respectively. Agro-climatically, this region is located in Maharashtra's drought prone zone.

3.5 Materials

3.5.1 Seeds

Seeds of Haliv (variety-Local) were used for sowing. It was made available through AICRP on MAP&B, M.P.K.V., Rahuri.

3.5.2 Rearing Materials

The laboratory material like rearing cages, glasswares, plastic vials, chemicals, cotton, muslin cloth, water pans, sugar solution (5 %), compound microscope, ocular micrometer etc. were provided by Department of Agricultural Entomology, Post Graduate Institute, M.P.K.V., Rahuri.

3.5.3 Pesticides

All the biopesticides and biorationals required for experiment were made available by Department of Agril. Entomology, M.P.K.V., Rahuri and AICRP on MAP & B, M.P.K.V., Rahuri.

3.5.4 Appliances

Manually operated knapsack sprayer fitted with hollow cone nozzle was used for spraying pesticide on Haliv, *Lepidium sativum.*

3.6 Methods

3.6.1 Biology of Mustard Sawfly, *Athalia lugens proxima* (Klug)

Biological and morphometrics parameters of *A. proxima* were studied at Post Graduate Laboratory, Department of Agricultural Entomology, M.P.K.V., Rahuri during 2020-2021.

3.6.1.1 Rearing of test insect

For biological study, the larvae of mustard sawfly were collected from the plot of AICRP on MAP & B, M.P.K.V, Rahuri. Collected larvae were kept in plastic bowls and covered with muslin cloth. To avoid fungal contamination, the food material was replaced daily in the morning hours until the larvae were ready to pupate. For pupation, the fully grown 6^{th} instar larvae were shifted to another plastic bowl containing leaves of haliv and sufficient soil and covered it with the help of muslin cloth. Muslin cloth was kept moist by sprinkling water on it. For survival of pupae, sufficient moisture was maintained inside the plastic bowl.

By examining presence of ovipositor and body size, male and female adults were distinguished. The adults which emerged from pupae were allowed to mate on the same day. These adults also used for further study. In each wooden rearing chamber, one pair of newly emerged female and male adult was released. Each rearing chamber contained the cotton swab dipped in 5 per cent sugar solution was suspended from the roof of rearing chamber by using cotton thread and pins to provide food to adults and 30 days old seedlings of Haliv provided for oviposition of mustard sawfly. Ten pairs of adults are taken in ten different wooden rearing chambers. The eggs were examined on a daily basis to record the incubation period of eggs, colour of eggs and also emergence of neonate larvae. At room temperature, all of the parameters were recorded.

3.6.1.2 Method of recording observations

3.6.1.2.1 Incubation period

A set of ten freshly laid eggs in three replications was daily examined for the emergence of neonates. The incubation period as well as egg colour variations also noted.

3.6.1.2.2 Larval period

Biological studies were conducted on larvae that newly hatched from eggs on the same day. Ten neonate larvae in three replications were put into petri plates containing leaves of Haliv using a camel hair brush. When full-grown larvae feeding stopped then became inactive. It was considered as the end of the larval stage and starting of pupal stage.

3.6.1.2.3 Pupal period

The fully grown 6^{th} instar larvae were placed in plastic bottle containing soil and covered it by muslin cloth. The pupal stage was documented through regular observations taken at morning time.

3.6.1.2.4 Oviposition period and fecundity

The adult male and female differentiated on the basis of size and presence of ovipositor. In each rearing chamber, one pair was released. Observations were recorded for ten pairs. The cotton swab dipped in 5 per cent sugar solution were provided as food for adults. These pairs were watched to note down the fecundity and oviposition duration of the female. The eggs laid per female were examined on daily basis until the

female death, in order to measure oviposition duration. The fecundity was calculated by counting total number of bulges on Haliv leaves with the help of magnifying lens.

3.6.1.2.5 Sex ratio

The emerged female and male adults were observed. They were counted to determine the sex ratio.

$$\text{Sex ratio} = \frac{\text{Total number of emerged male adults}}{\text{Total number of emerged female adults}}$$

3.6.1.2.6 Adult longevity

Both male and female adults were watched daily for determination of longevity from the time they were emerged until they died.

The observations were recorded under microscope regarding shape, colour, size of egg, larvae, pupa and adults. Ocular micrometer is used to measure the length and breadth of eggs and first instar larvae. The length and width of second, third, fourth, fifth and sixth instar larvae, pupa and adult females and males were measured by Graph paper and scale.

3.6.2 To Study the Bioefficacy of Plant Products and Bio-pesticides Against Mustard Sawfly on Haliv, *Lepidium sativum*

The experimental study conducted on the farm of AICRP on MAP & B., Mahatma Phule Krishi Vidyapeeth, Rahuri to evaluate biopesticides and biorationals and laid out in Randomized Block Design (RBD) with seven treatments replicated three times using local variety of garden cress (Haliv). From each plot, five plants were selected at random and tagged and data were recorded. The plan of layout of experiment is given in Fig. 3.1

3.6.2.1 Details of experiment

1.	Season and year	:	*Rabi* 2020-21
2.	Crop	:	Haliv, *Lepidium sativum*
3.	Variety	:	Local
4.	Design	:	Randomized Block Design
5.	Number of treatments	:	7
6.	Number of replications	:	3
7.	Spacing	:	45 cm x 10 cm
8.	Plot size	:	4 m x 3 m
9.	Date of Sowing	:	26-11-2020
10.	Fertilizer dose	:	80 kg:80kg:30 kg (N:P:K/ha)

11.	Date of biopesticide application	:	
	1st spray	:	19-01-2021
	2nd spray	:	03-02-2021
12.	Date of harvesting	:	28-03-2021

3.6.2.2 Method of applications of biopesticides and plant products

The first spray of respective biopesticides or biorational pesticides was taken during maximum activity of mustard sawfly and second sprays were taken at 15th day after first spraying. Spraying was done using manually operated knapsack sprayer with hollow cone nozzle with 500 lit. water/ha at morning time. For preparation of spray solution, the known quantity of biopesticides or biorational pesticides were measured and taken in small container and mixed thoroughly with required concentration of spray solution was prepared with known quantity of water, agitated and then poured into the tank of sprayer. For application of NSE 5 %, 500 g powder of NSE 5 % was soaked overnight in ten litre of water and stock solution filtered with the help of muslin cloth. The spray pump was washed before spraying. The spray pump was washed thoroughly after each spray of plant products or biopesticides. The next treatment spraying was carried out as above manner.

Table 3.1. Treatment details for field trial on Haliv, *Lepidium sativum*

Tr. No.	Treatments	Dose g/ ml/L water	Source
T_1	Azadirachtin 10000 ppm	2 ml	T. Stanes and Co. Ltd., Coimbatore
T_2	*Bt* (*Bacillus thuringiensis*)	2 ml	Sumitomo Chemical India Pvt. Ltd., Gujarat
T_3	NSE 5 %	50 g	Giridhar Agro Pvt. Ltd., Lasalgaon, Nashik (M.S.)
T_4	*Metarhizium anisopliae* 1.15 % WP	5 g	Biocontrol Research Laboratory, Department of Agril. Entomology M.P.K.V., Rahuri, Ahmednagar (M.S.)
T_5	*Beauveria bassiana* 1.15 % WP	5 g	Biocontrol Research Laboratory, Department of Agricultural Entomology, M.P.K.V., Rahuri, Ahmednagar (M.S.)
T_6	Karanj oil	2 ml	Vijaya Agro-Industries, Sangamner, Ahmednagar (M.S.)
T_7	Untreated control	-	

3.6.2.3 Methods of recording observations

Five plants in each plot were chosen at random and tagged to record observations on surviving larval population. The pre-treatment count of larval population was recorded one day before spray. Post treatment counts were taken after three, seven and fourteen days of each spraying. After two sprays, the per cent reduction in larval population as compared to pre-treatment count were calculated.

The data on marketable seed yield measured in kg/plot from which the seed yield in q/ha was calculated. By using the following formula, the increase in yield over control in each treatment were calculated.

$$\text{Increase in yield over control} = \frac{\text{Yield in treatment plot} - \text{Yield in control plot}}{\text{Yield in control plot}} \times 100$$

The data of surviving mustard sawfly population recorded from five randomly selected plants from each plot was transformed into square root transformation values and then data were subjected to statistical analysis that given by Panse and Sukhatme (1985). The standard error (S.E.) and critical difference (C.D.) at 5 per cent level of probability were calculated to determine the efficacy of each biorationals and biopesticides.

3.6.2.4 Incremental cost benefit ratio and B:C ratio

The incremental cost benefit ratio of each biopesticide and plant products treatment was calculated by considering the prevailing market price of input, produce and labour charges for insecticide application and the net income gained from each treatment over control. B:C ratio of every biopesticide and biorationals treatment was calculated by using gross returns and cost of cultivation.

4. RESULTS AND DISCUSSION

The studies on "Biology and ecofriendly management of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv, *Lepidium sativum*" were conducted and results and discussion are presented in this chapter.

4.1 Biology of Mustard Sawfly, *Athalia lugens proxima (*Klug)

Biological and morphometrics parameters of *Athalia lugens proxima* were studied at Post Graduate Laboratory, Department of Agricultural Entomology, M.P.K.V., Rahuri during 2020-2021.

Mustard sawfly is a hymenopteran pest which undergoes complete metamorphosis having egg, larva, pupa and adult as different life stages. The results pertaining to developmental period of several life stages of *Athalia lugens proxima* (Klug) were shown in Table 4.1 and observations on morphometrics were shown in Table 4.2.

4.1.1 Egg Stage

The female adult fly of *Athalia lugens proxima* (Klug) laid eggs singly, in slits made with saw like ovipositor along the under sides of the leaf margin. Freshly laid eggs were smooth, creamy white and oval shape which later turned to black. The incubation period was varied between 6 to 8 days with mean incubation period of 6.95 ± 0.69 days (Table 4.1). The findings are in line with the observations of Kapadia *et al*. (1980) who observed incubation period of 6.21 days under laboratory conditions.

In case of size of the eggs, the average length and breadth were measured to be 0.44 ± 0.01 and 0.23 ± 0.01 mm, respectively (Table 4.2). The present findings are more or less similar to Shirke *et al.* (1968) who reported that average length and width of eggs of mustard sawfly on radish 0.66 and 0.35 mm, respectively.

4.1.2 Larval Stage

The larva passed through six instars. Larvae had three thoracic pairs of legs with eight pairs of abdominal prolegs. Crochets were absent in prolegs. Larvae on touch suddenly fall to ground and shown feign death behaviour. The numbers of exuviae formed during every moulting were used to identify larval instars. To study the various larval instars of *Athalia lugens proxima* (Klug) under laboratory conditions, larva that

have recently hatched were reared individually in medium sized petri plates by providing food of fresh leaves of Haliv.

4.1.2.1 First instar

The freshly hatched larva was very small. Body was greyish green in colour. Head was black in colour. Body divided into head, thorax and abdomen region. Thorax had three pairs of legs and abdomen had eight pairs of prolegs were also observed. The duration of 1st instar larvae ranged from 3 to 4 days with a mean of 3.25 ± 0.44 days (Table 4.1). In past, Patil and Pokharkar (1973) reported that duration of first instar larva of *Athalia lugens proxima* (Klug) was 2.5 days that reared on radish which is more or less in line with the present findings.

The mean length of first instar larva was 2.0 ± 0.01 mm and average width was 0.38 ± 0.01 mm (Table 4.2). The present work is in conformation with findings of Kapadia *et al.* (1980) and Sumithramma *et al.* (1997).

4.1.2.2 Second instar

Second instar larva was greyish green with black head. Excreta were green to black colour. This instar was more active than previous instar. The duration ranged from 1 to 3 days with mean duration of 2nd instar larvae ranged from 1.90 ± 0.64 days (Table 4.1). According to Patil and Pokharkar (1973), the mean duration of second instar larva of *Athalia lugens proxima (*Klug) was 1.80 days which is close to present findings.

Second instar had mean length of 3.40 ± 0.50 mm and average width of 0.69 ± 0.01 mm (Table 4.2). The current present findings are in conformation with findings of Sumithramma *et al.* (1997) who reported morphometrics of second instar larva of *Athalia lugens proxima* (Klug) (3.78 mm x 0.71 mm).

4.1.2.3 Third instar

It was blackish grey with black head. A narrow dark black median line started from mesothorax to tip of abdomen appeared on the dorsal region. Two lateral lines of black spots, one on each side, running from near the head to last segment of abdomen. The duration ranged from 1 to 3 days. The average period was 1.60 ± 0.68 days (Table 4.1). Previously, mean period of 1.85 ± 0.36 days reported by Sumithramma *et al.* (1997) which is in support to present investigation.

Length of third instar larvae was 5.35 ± 0.59 mm. Its width was 1.0 ± 0.01 mm (Table 4.2). The current study is in agreement with Sumithramma *et al.* (1997) who measured that the mean length and width of third instar larva were 5.20 and 1.02 mm, respectively.

4.1.2.4 Fourth instar

The colour of fourth instar was same as third instar. Two rows of black spots and more darker mid dorsal line when compared with third instar. Its duration ranged from 1 to 3 days. It had mean duration of 2.0 ± 0.56 days (Table 4.1). According to Sumithramma *et al.* (1997), the mean duration of fourth instar larva of *Athalia lugens proxima* (Klug) was 1.85 ± 0.48 days which is more or less in support to present investigations. At this stage the larva measured 8.15 ± 1.35 mm in length and 1.70 ± 0.47 mm in width (Table 4.2). The results are in support to Sumithramma *et al.* (1997) who recorded the length and width of *Athalia lugens proxima* (Klug) were 7.81 and 1.40 mm, respectively when reared on mustard.

4.1.2.5 Fifth instar

This instar was voracious feeder on haliv. The head and body were both black in colour. Feign death behaviour was observed when touch to larva. Its duration ranged from 2 to 3 days with mean period of 2.60 ± 0.50 days (Table 4.1). Previously, mean duration of 2.90 ± 0.44 days for fifth instar was noticed by Sumithramma *et al.* (1997) which is close to present investigation.

At this stage the larva measured 11.65 ± 1.53 mm in length and 2.20 ± 0.41 mm in width (Table 4.2). The present findings are more or less in conformation with findings of Sumithramma *et al.* (1997) who reported that average length was 11.62 mm while average width was 2.06 mm for 5^{th} instar larvae of *Athalia lugens proxima* (Klug).

4.1.2.6 Sixth instar

This instar became sluggish. Both head and body were black coloured. It had duration of 1 to 3 days with mean duration of 1.30 ± 0.66 days (Table 4.1). Formerly, mean duration was reported as 1.55 ± 0.51 days by Sumithramma *et al.* (1997) which is in accordance to present investigation.

At this stage the larva measured 14.0 ± 1.75 mm in length and 2.55 ± 0.51 mm in width (Table 4.2). Similar observations were noticed by Jagtap and Kadam (1978) who reported length of six instar larva was 14.24 mm.

4.1.2.7 Total larval period

The entire duration of larvae ranges from 9 to 19 days. The average larval period was 12.65 ± 1.95 days (Table 4.1). The present findings are more or less in agreement with the findings of Singh and Sachan (1997) found that at the temperature of 20, 25 and 30°C larvae lasted 13.7, 11.4 and 12.4 days, respectively. On mustard, Bogawat (1967) found a 12 days larval phase.

4.1.3 Pupal Stage

Pupa was exarate type. Pupation of *Athalia lugens proxima* (Klug) took inside earthen cocoon in the soil. Six instar larvae after moulting construct earthen cocoon and undergoes pupation into it. Body becomes short by contraction. Pupal duration ranged between 10 to 15 days with mean duration of 12.25 ± 1.37 days (Table 4.1). According to Dhillon (1966), Kapadia *et al.* (1980) and Sahu *et al*. (2018) recorded the duration of pupa of *Athalia lugens proxima* (Klug) was 10 to 15 days. Kapadia *et al.* (1980) reported that mean duration of pupa of *Athalia lugens proxima* (Klug) was 12.79 days. The results of current finding are more or less in line with the above reports.

The pupa was 7.70 ± 0.47 mm long and 4.50 ± 0.51 mm broad (Table 4.2). The present study is in accordance with Sumithramma *et al*. (1997) who recorded length of pupae reared on mustard was 7.53 mm.

4.1.4 Adult Stage

Male adult of *Athalia lugens proxima* (Klug) was more active and smaller than female. It had black head. Prothorax was orange in colour and pterothorax was black in colour. Two pairs of wings were smoky with black veins. Abdomen was orange coloured. Male longevity ranged from 3 to 18 days. The average male longevity was 13.50 ± 4.09 days (Table 4.1). Adult males fed on mustard survived for 13.20 ± 3.32 days, according to Sumithramma *et al*. (1997) which is in line with present study. The male adult was 5.50 ± 0.53 mm in length and its breadth was 1.70 ± 0.48 mm (Table 4.2). The present study is in accordance with Jagtap and Kadam (1978) measured length of adult male was 5.19 mm and Sumithramma *et al*. (1997) who recorded breadth of adult

male was 1.79 mm when reared on mustard. Male had wing expansion of 12.0 ± 0.82 mm (Table 4.2) which is more or less in line with Kapadia *et al*. (1980) as they measured wing expansion of male as 10.78 mm.

The colour of adult female and male adult are same. Female was thicker than male and showed presence of saw-like black ovipositor on ventral side at tip of abdomen. Female longevity ranged from 2 to 13 days with average longevity of 9.75 ± 3.51 days (Table 4.1). The findings of this study are similar to those of Bogawat (1967) who discovered that the mean survival time of adult female was 11 days. The female adult was 6.60 ± 0.52 mm long and 2.20 ± 0.42 mm broad (Table 4.2). The present study is in accordance with Jagtap and Kadam (1978) investigated length of adult female was 6.61 mm and breadth of adult female reared on mustard was 2.17 mm recorded by Sumithramma *et al*. (1997). Female had wing expansion of 15.20 ± 0.79 mm (Table 4.2) which is more or less in line with Kapadia *et al*. (1980) recorded wing expansion of female as 12.20 mm.

4.1.5 Pre-oviposition Period

It ranged from 2 to 7 hours with an average of 5.15 ± 1.42 hours (Table 4.1) which is similar to observations of Sumithramma *et al*. (1997) recorded average pre-oviposition duration as 5.3 hours on mustard.

4.1.6 Oviposition Period

The oviposition period of adult female of *Athalia lugens proxima* (Klug) ranged from 2 to 7 days with an average 5.95 ± 1.47 days (Table 4.1). On mustard, Bogawat (1967) found a 6.75 days oviposition duration which is close to present findings.

4.1.7 Post-oviposition Period

The post oviposition period of adult female of *Athalia lugens proxima* (Klug) ranged from 0 to 6 days with an average 3.80 ± 2.35 days (Table 4.1).

4.1.8 Longevity of Adults

Male longevity found more than that of female. Mean longevity of male adult was observed to be 13.5 ± 4.09 days. For female, the longevity was 9.75 ± 3.51 days (Table 4.1). More or less similar observations recorded by Sumithramma *et al.* (1997) and Bogawat (1967).

Table 4.1. Developmental period of different life stages of mustard sawfly, *Athalia lugens proxima* (Klug) on *Lepidium sativum*

Sr. No.	Stage	Mean ± SD (Days)	Range (Days)
1.	Incubation period of eggs	6.95 ± 0.69	6-8
2.	Hatchability (%)	86.67	
3.	Fecundity in numbers	74.60	
4.	Larva		
	1st instar	3.25 ± 0.44	3-4
	2nd instar	1.90 ± 0.64	1-3
	3rd instar	1.60 ± 0.68	1-3
	4th instar	2.00 ± 0.56	1-3
	5th instar	2.60 ± 0.50	2-3
	6th instar	1.30 ± 0.66	1-3
	Total larval period	12.65 ± 1.95	9-19
5.	Pupa	12.25 ± 1.37	10-15
6.	Total period taken from egg to adult emergence	31.85 ± 3.28	25-42
7.	Adult		
	Male	13.5 ± 4.09	3-18
	Female	9.75 ± 3.51	2-13
8.	Pre-oviposition period in hours	5.15 ± 1.42	2-7
9.	Oviposition period in days	5.95 ± 1.47	2-7
10.	Post oviposition period in days	3.80 ± 2.35	0-6
11.	Total life span in days		
	Male	45.35 ± 6.45	28-60
	Female	41.60 ± 5.69	27-55
12.	Sex ratio (Male: Female)	1 : 2.33	

4.1.9 Fecundity

The fecundity of *Athalia lugens proxima* (Klug) ranged from 23 to 127 eggs per female with an average of 74.60 eggs deposited by a single female. Under

controlled condition, Ahuja and Sehgal (1982) found that female deposited 77.70 ± 5.99 eggs over her lifetime which is in line with current findings.

4.1.10 Hatchability

Hatchability of eggs of *Athalia lugens proxima* (Klug) was 86.67 per cent (Table 4.1). Similar findings were recorded by Shirke *et al*. (1968) observed the hatchability of eggs ranged from 80.1 to 91 per cent.

4.1.11 Sex Ratio

It was 1:2.33 (adult male : adult female) (Table 4.1). According to Jagtap and Kadam (1978), a sex ratio of 1:2.6 (male : female) which is close to present study.

4.1.12 Egg to Adult Emergence

Total period required from egg stage to adult emergence was varied from 25 to 42 days with mean period of 31.85 ± 3.28 days (Table 4.1). The present investigation was in line with Sumithramma *et al*. (1997) as they observed 29.10 ± 1.15 days of time period from egg stage to adult emergence.

4.1.13 Total Life Span

The average life span of male and female mustard sawfly was observed to be 45.35 ± 6.45 and 41.60 ± 5.69 days, respectively (Table 4.1).

Table 4.2. Measurements of different life stages of mustard sawfly, *Athalia lugens proxima* (Klug) on *Lepidium sativum*

Stage		Average length (mm)	Average width (mm)
Eggs*		0.44 ± 0.01	0.23 ± 0.01
Larva	1st instar	2.00 ± 0.01	0.38 ± 0.01
	2nd instar	3.40 ± 0.50	0.69 ± 0.01
	3rd instar	5.35 ± 0.59	1.00 ± 0.01
	4th instar	8.15 ± 1.35	1.70 ± 0.47
	5th instar	11.65 ± 1.53	2.20 ± 0.41
	6th instar	14.00 ± 1.75	2.55 ± 0.51
Pupa		7.70 ± 0.47	4.50 ± 0.51
Adult	Male	5.50 ± 0.53	1.70 ± 0.48
	Female	6.60 ± 0.52	2.20 ± 0.42
Wing expansion	Male	-	12.00 ± 0.82
	Female	-	15.20 ± 0.79

* Observations taken at 10 X magnification power

4.2 Bioefficacy of Biopesticides and Plant Products Against Mustard Sawfly

Field experiment conducted on the experimental farm of AICRP on MAP&B, M.P.K.V., Rahuri (M.S.) during *rabi* 2020-21. For evaluation of biopesticides and plant products, the experiment was set up in a Randomized Block Design (RBD) with 7 treatments replicated 3 times using Local variety of haliv. The five plants were selected at random and tagged from each plot and then observations were recorded by counting per plant surviving mustard sawfly population.

The data on mustard sawfly population per plant of haliv one day before application *i.e.* pre-count and post-count at 3rd, 7th and 14th days after 1st and 2nd spray applications. The mean of two applications is presented in Table 4.3 to 4.5.

4.2.1 First Spray

4.2.1.1 At 1 day before spray (pre count)

The infestation of mustard sawfly varied from 8.67 to 9.07 larvae per plant, which were statistically non-significant according to the data shown in Table 4.3.

4.2.1.2 At 3 days after spraying

Significant results obtained on 3rd day after application of first spray. Among all treatments, T_1 (Azadirachtin 10000 ppm @ 2 ml/lit. water) showed to be the most promising treatment which recorded 5.80 mustard sawfly larvae per plant and treatment T_1 found at par with treatment T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit. water (6.00 mustard sawfly larvae per plant), followed by T_6 Karanj oil @ 2 ml/lit. water (7.47 mustard sawfly larvae per plant), T_3 NSE 5 % @ 50 g/lit. water (7.53 mustard sawfly larvae per plant), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (8.53 mustard sawfly larvae per plant) and T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (8.60 mustard sawfly larvae per plant). Whereas, untreated control recorded highest 9.07 mustard sawfly larvae per plant.

4.2.1.3 At 7 days after spraying

Among all treatments, T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water found to be superior treatment which recorded 4.27 mustard sawfly larvae per plant and treatment T_5 found at par with treatment T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (4.33 mustard sawfly larvae per plant), T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit. water (4.40 mustard sawfly larvae per plant), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit.

water (4.80 mustard sawfly larvae per plant) and followed by treatment T_6 Karanj oil @ 2 ml/lit. water (6.07 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (6.93 mustard sawfly larvae per plant). The untreated control had highest population with 8.93 mustard sawfly larvae per plant.

4.2.1.4 At 14 days after spraying

Among all treatments, T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit. water showed to be significantly superior treatment which recorded 2.93 mustard sawfly larvae per plant and treatment T_2 found at par with T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (3.07 mustard sawfly larvae per plant) and followed by T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (3.47 mustard sawfly larvae per plant), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (3.80 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (6.53 mustard sawfly larvae per plant). The largest number of mustard sawfly larvae per plant was found in the untreated control which was 8.73.

Table 4.3. Management of mustard sawfly, *Athalia lugens proxima* (Klug) after first spray on *Lepidium sativum*

Sr. No.	Treatments	Dose g/ ml/L of water	Average number of survival population of mustard sawfly/ plant				Per cent reduction in pest population
			PTC	3 DAS	7 DAS	14 DAS	
T_1	Azadirachtin 10000 ppm	2 ml	8.80 (3.05)	5.80 (2.51)	4.33 (2.20)	3.80 (2.07)	56.82
T_2	*Bt* (*Bacillus thuringiensis*)	2 ml	9.07 (3.09)	6.00 (2.55)	4.40 (2.21)	2.93 (1.85)	67.70
T_3	NSE 5 %	50 g	8.93 (3.07)	7.53 (2.83)	6.93 (2.72)	6.53 (2.65)	26.88
T_4	*Metarhizium anisopliae* 1.15 % WP	5 g	8.67 (3.03)	8.53 (3.00)	4.80 (2.30)	3.47 (1.99)	59.98
T_5	*Beauveria bassiana* 1.15 % WP	5 g	8.80 (3.05)	8.60 (3.02)	4.27 (2.18)	3.07 (1.89)	65.11
T_6	Karanj oil	2 ml	8.73 (3.04)	7.47 (2.82)	6.07 (2.56)	5.67 (2.48)	35.05
T_7	Untreated control	-	8.80 (3.05)	9.07 (3.09)	8.93 (3.07)	8.73 (3.04)	-
	S.E. ±		0.049	0.051	0.050	0.040	
	CD @ 5%		NS	0.160	0.140	0.110	

Note : 1. DAS means Days after spray
2. PTC means Pre-treatment count
3. Figures in the parenthesis are transformed values of $\sqrt{(x + 0.5)}$ where x is original value

From the data on per cent reduction in mustard sawfly larval population over pre-count after first spray, the different treatments are listed in descending order in reducing larval population as *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water (67.70), *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (65.11), *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (59.98), Azadirachtin 10000 ppm @ 2 ml/lit. water (56.82), Karanj oil @ 2 ml/lit. water (35.05) and NSE 5 % @ 50 g/lit. water (26.88).

4.2.2 Second Spray

Table 4.4 shows that at 3rd, 7th and 14th days after second application, all plant products and biopesticides treatments against mustard sawfly found significantly superior as compared to untreated control.

4.2.2.1 At 3 days after spraying

Among all treatments, T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit. water showed to be the significantly superior treatment that recorded 1.87 mustard sawfly larvae per plant, followed by T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (2.40 mustard sawfly larvae per plant), T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (3.00 mustard sawfly larvae per plant), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (3.34 mustard sawfly larvae per plant), T_6 Karanj oil @ 2 ml/lit. water (4.80 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (5.53 mustard sawfly larvae per plant).Whereas, untreated control recorded highest of 8.47 mustard sawfly larvae per plant.

4.2.2.2 At 7 days after spraying

Among all treatments, the treatments T_2 (*Bt*, *Bacillus thuringiensis*@ 2 ml/lit. water) and T_5 (*Beauveria bassiana* 1.15 % WP @ 5 g/lit. water) were equally effective which recorded 1.47 mustard sawfly larvae per plant and these treatments were followed, by T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (1.87 mustard sawfly larvae per plant) and T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (1.87 mustard sawfly larvae per plant), T_6 Karanj oil @ 2 ml/lit. water (4.00 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (5.00 mustard sawfly larvae per plant).Whereas, untreated control plants had the highest population with 8.33 mustard sawfly larvae per plant.

Table 4.4. Management of mustard sawfly, *Athalia lugens proxima* (Klug) after second spray on *Lepidium sativum*

Sr. No.	Treatments	Dose g/ ml/L of water	Average number of survival population of mustard sawfly/ plant			Per cent reduction in pest population
			3 DAS	7 DAS	14 DAS	
T_1	Azadirachtin 10000 ppm	2 ml	2.40 (1.70)	1.87 (1.54)	1.67 (1.47)	56.05
T_2	*Bt* (*Bacillus thuringiensis*)	2 ml	1.87 (1.54)	1.47 (1.40)	0.93 (1.20)	68.26
T_3	NSE 5 %	50 g	5.53 (2.45)	5.00 (2.34)	4.80 (2.30)	26.49
T_4	*Metarhizium anisopliae* 1.15 % WP	5 g	3.34 (1.96)	1.87 (1.54)	1.40 (1.38)	59.65
T_5	*Beauveria bassiana* 1.15 % WP	5 g	3.00 (1.87)	1.47 (1.40)	1.13 (1.28)	63.19
T_6	Karanj oil	2 ml	4.80 (2.30)	4.00 (2.12)	3.73 (2.06)	34.21
T_7	Untreated control	-	8.47 (2.99)	8.33 (2.97)	8.07 (2.93)	-
	S.E. ±		0.040	0.030	0.040	
	CD @ 5%		0.110	0.090	0.110	

Note : 1. DAS means Days after spray
2. Figures in the parenthesis are transformed values of $\sqrt{(x + 0.5)}$ where x is original value

4.2.2.3 At 14 days after spraying

Among all treatments, T_2 (*Bt, Bacillus thuringiensis* @ 2 ml/lit. water) (0.93 mustard sawfly larvae per plant) showed to be the best treatment and at par with treatment T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (1.13 mustard sawfly larvae per plant), followed by T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (1.40 mustard sawfly larvae per plant), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (1.67 mustard sawfly larvae per plant), T_6 Karanj oil @ 2 ml/lit. water (3.73 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (4.80 mustard sawfly larvae per plant). Whereas, untreated control recorded highest 8.07 mustard sawfly larvae per plant.

From the data on per cent reduction in mustard sawfly larval population over pre count after second spray, the different treatments are listed in descending order in reducing larval population as *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit. water (68.26), *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (63.19), *Metarhizium anisopliae* 1.15 %

WP @ 5 g/lit. water (59.65), Azadirachtin 10000 ppm @ 2 ml/lit. water (56.05), Karanj oil @ 2 ml/lit. water (34.21) and NSE 5 % @ 50 g/lit. water (26.49).

4.2.3 Cumulative Effect of Biopesticides and Plant Products Against Mustard Sawfly

Table 4.5 shows the average data from two applications on the per cent reduction in pest population of mustard sawfly, revealing that all the bio-pesticides or plant products treatments were significantly superior to the untreated control.

Table 4.5. Cumulative effect of biopesticides and plant products against mustard sawfly on *Lepidium sativum*

Sr. No.	Treatments	Dose g/ ml/L of water	Average number of survival population of mustard sawfly/ plant			Per cent reduction in pest population
			3 DAS	7 DAS	14 DAS	
T_1	Azadirachtin 10000 ppm	2 ml	4.10 (2.14)	3.10 (1.90)	2.73 (1.80)	56.43
T_2	*Bt* (*Bacillus thuringiensis*)	2 ml	3.93 (2.10)	2.93 (1.85)	1.93 (1.56)	67.98
T_3	NSE 5 %	50 g	6.53 (2.65)	5.96 (2.54)	5.66 (2.48)	26.68
T_4	*Metarhizium anisopliae* 1.15 % WP	5 g	5.93 (2.54)	3.33 (1.96)	2.43 (1.71)	59.82
T_5	*Beauveria bassiana* 1.15 % WP	5 g	5.80 (2.51)	2.87 (1.84)	2.10 (1.61)	64.15
T_6	Karanj oil	2 ml	6.13 (2.57	5.03 (2.35)	4.70 (2.28)	34.63
T_7	Untreated control	-	8.77 (3.04)	8.63 (3.02)	8.40 (2.98)	-
	S.E. ±		0.040	0.040	0.040	
	CD @ 5%		0.140	0.120	0.110	

Note : 1. DAS means Days after spray
2. Figures in the parenthesis are transformed values of $\sqrt{(x + 0.5)}$ where x is original value

4.2.3.1 At 3 days after spraying

Among all treatments, T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit water showed to be most outstanding treatment which recorded 3.93 mustard sawfly larvae per plant and that was at par with the treatment T_1 Azadirachtin 10000 ppm @ 2 ml/lit water (4.10 mustard sawfly larvae per plant), followed by T_5 *Beauveria bassiana* 1.15 % WP

@ 5 g/lit water (5.80 mustard sawfly larvae per plant), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (5.93 mustard sawfly larvae per plant), T_6 Karanj oil @ 2 ml/lit. water (6.13 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (6.53 mustard sawfly larvae per plant). Whereas, untreated control recorded highest 8.77 mustard sawfly larvae per plant.

4.2.3.2 At 7 days after spraying

Among all treatments, T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water showed to be the most promising treatment which recorded 2.87 mustard sawfly larvae per plant and statistically found at par with T_2 treatment *Bt*, *Bacillus thuringiensis* @ 2 ml/lit. water (2.93 mustard sawfly larvae per plant), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (3.10 mustard sawfly larvae per plant), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (3.33 mustard sawfly larvae per plant) followed by T_6 Karanj oil @ 2 ml/lit. water (5.03 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50g / lit. water (5.96 mustard sawfly larvae per plant). Untreated control plants had largest population with 8.63 mustard sawfly larvae per plant.

4.2.3.3 At 14 days after spraying

Among all treatments, T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit water showed to be the most promising treatment which recorded 1.93 mustard sawfly larvae per plant and statistically found at par with T_5 treatment that is *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (2.10 mustard sawfly larva per plant) followed by T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (2.43 mustard sawfly larvae per plant), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (2.73 mustard sawfly larvae per plant), T_6 Karanj oil @ 2 ml/lit. water (4.70 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (5.66 mustard sawfly larvae per plant). Whereas, untreated control recorded highest 8.40 mustard sawfly larvae per plant.

From the data on per cent reduction in mustard sawfly larval population over pre count after two sprays, the different treatments are listed in descending order for reducing larval population as *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water (67.98), *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (64.15), *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (59.82), Azadirachtin 10000 ppm @ 2 ml/lit. water (56.43), Karanj oil @ 2 ml/lit. water (34.63) and NSE 5 % @ 50 g/lit. water (26.68).

From the present investigation, *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water was the best biopesticide to control mustard sawfly and it reduced mustard sawfly larval population upto 67.98 per cent. Hasan and Singh (2009) studied that Halt (*Bacillus thuringiensis*) was effective against mustard sawfly.

The per cent reduction in mustard sawfly larval population caused by *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (64.15) was in agreement with Pradhan *et al.* (2020) who recorded 67.11 per cent reduction in mustard sawfly larval population over control.

The per cent reduction in larval population of mustard sawfly caused by *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water was 59.82 per cent which was in agreement with Pradhan *et al.* (2020) who investigated that 61.48 per cent reduction in mustard sawfly larval population over control on *Brassica campestris var. Toria* caused by *Metarhizium anisopliae* @ 5 g/lit.

The per cent reduction in mustard sawfly larval population caused by Azadirachtin 10000 ppm @ 2 ml/lit. water (56.43) was close to results of Pradhan *et al.* (2020) who recorded 57.88 per cent reduction in mustard sawfly larval population over control caused by Azadirachtin 1500 ppm @ 2 ml/lit in *Brassica campestris var. Toria.*

The per cent reduction in population in mustard sawfly larvae caused by NSE 5 % @ 50 g /lit. water (26.68) was nearly similar to results of Kalsaria and Parmar (2019) who recorded 33.12 per cent mean mortality of mustard sawfly caused by NSKE 5 %.

4.3 Effect of Different Biopesticides and Plant Products Against Mustard Sawfly on Seed Yield of Haliv

The marketable seed yield of Haliv are given in Table 4.6. All biopesticides and biorational pesticides were statistically superior over untreated control. The seed yield of Haliv using different treatments varied from 12.07 to 17.49 q/ha. Among all treatments, the highest seed yield of 17.49 q/ha was produced by T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. water) and followed by T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (16.18 q/ha), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (15.42 q/ha), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (14.65 q/ha), T_6 Karanj oil @

2 ml/lit. water (13.83 q/ha) and T_3 NSE 5 % @ 50 g/lit. water (12.89 q/ha). However, the lowest seed yield (12.07 q /ha) was recorded in the untreated control.

It is reported that, per cent increase in seed yield was highest (44.90) due to application of T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/ lit. of water) and it was followed by, T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (34.05), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (27.75), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (21.38), T_6 Karanj oil @ 2 ml/lit. water (14.58) and T_3 NSE 5 % @ 50 g/lit. water (6.79).

Table 4.6 Effect of different biopesticides and plant products against mustard sawfly on seed yield of Haliv, *Lepidium sativum*

Sr. No.	Treatments	Seed yield (q/ha)	Per cent increase in seed yield over control
T_1	Azadirachtin 10000 ppm	14.65	21.38
T_2	*Bt* (*Bacillus thuringiensis*)	17.49	44.90
T_3	NSE 5 %	12.89	6.79
T_4	*Metarhizium anisopliae* 1.15 % WP	15.42	27.75
T_5	*Beauveria bassiana* 1.15 % WP	16.18	34.05
T_6	Karanj oil	13.83	14.58
T_7	Untreated control	12.07	-
	S.E. ±	0.28	-
	CD @ 5%	0.87	-

4.4 Incremental Cost Benefit Ratio (ICBR) and B:C Ratio of Different Bio-pesticides and Plant Products Against Mustard Sawfly

The data generated on incremental cost benefit ratio and B:C ratio of different biopesticides and plant products applied on Haliv against mustard sawfly presented in Table 4.7.

As regards the incremental cost benefit ratio among all treatments, the highest ICBR (1:9.96) was recorded in T_5 *Beauveria bassiana* 1.15% WP @ 5 g/lit. water and it was followed by, T_2 *Bt, Bacillus thuringiensis* @ 2 ml/lit. of water (1:8.85), T_4

Table 4.7. Incremental cost benefit ratio (ICBR) and B:C ratio of different biopesticides and plant products against mustard sawfly on *Lepidium sativum*

Sr. No.	Treatments	Marketable seed yield (q/ ha)	Additional yield over control (q/ ha)	Additional income over control (Rs/ha)	Cost of protection (Rs/ha)	Total cost of cultivation (Rs/ha)	Gross monitory returns (Rs/ha)	Net monitory returns (Rs/ha)	B:C ratio	ICBR
1.	Azadirachtin 10000 ppm	14.65	2.58	20640	4400	61885	117200	55315	1:1.89	1:3.69
2.	*Bt (Bacillus thuringiensis)*	17.49	5.42	43360	4400	61885	139920	78035	1:2.26	1:8.85
3.	NSE 5 %	12.89	0.82	6560	2750	60235	103120	42885	1:1.71	1:1.38
4.	*Metarhizium anisopliae* 1.15 % WP	15.42	3.35	26800	3000	60485	123360	62875	1:2.04	1:7.93
5.	*Beauveria bassiana* 1.15 % WP	16.18	4.11	32880	3000	60485	129440	68955	1:2.14	1:9.96
6.	Karanj oil	13.83	1.76	14080	8000	65485	110640	45155	1:1.69	1:0.76
7.	Untreated control	12.07	-	-	-	57485	96560	39075	1:1.67	-

Treatment cost = Cost of biopesticides or biorationals pesticides + Charges of biopesticides pesticides application (Labour charges)

Azadirachtin 10000 ppm **:** Rs. 1200/lit Karanj oil **:** Rs 6000/lit *Metarhizium anisopliae* 1.15 % WP **:** Rs 200/kg

Bt (Bacillus thuringiensis) **:** Rs. 1200/lit NSE 5 % **:** Rs 15/kg *Beauveria bassiana* 1.15 % WP **:** Rs200/kg

Marketable price of Haliv seeds : Rs 80/kg Labour cost @ Rs 1000/ha/spray

Metarhizium anisopliae 1.15 % WP @ 5 g/lit. water (1:7.93), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (1:3.69), T_3 NSE 5 % @ 50 g/lit. water (1:1.38), T_6 Karanj oil @ 2 ml/lit. water (1:0.76).

Kalsaria and Parmar (2019) were recorded 1:3.1 ICBR ratio with application of (*B. bassiana* 2.5 kg/ha + Acetamiprid 20 % SP+ Spinosad 45 % SC + cypermethrin 4 % EC) and (NSKE 5 % + Monocrotophos 36 % SL + Quinolphos 25 % EC +Ethion 40 + Cypermethrin % EC) against mustard sawfly infesting mustard.

The present investigation revealed that, T_2 *Bt* (*Bacillus thuringiensis* @ 2ml/lit. of water) with B:C ratio (1:2.26) was highest among all treatments and it was followed by T_5 *Beauveria bassiana* 1.15 % WP @ 5g/lit. water (1:2.14), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (1:2.04), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (1:1.89), T_3 NSE 5 % @ 50 g/lit. water (1:1.71), T_6 Karanj oil @ 2 ml/lit. water (1:1.69) and T_7 untreated control (1:1.67).

Pradhan *et al*. (2020) recorded B:C ratio against major insect pests of *Brassica campestris var. toria* as 1:2.25, 1:2.15 and 1:2.06 for treatments *Beauveria bassiana*, *Metarhizium anisopliae* and Azadirachtin, respectively.

5. SUMMARY AND CONCLUSIONS

The present investigation entitled *"*Biology and ecofriendly management of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv, *Lepidium sativum*" was conducted during *rabi* 2020-21. The biology of *Athalia lugens proxima* was conducted under laboratory conditions and management at field conditions. In India, there were no references on research work carried out about biology and eco-friendly management of mustard sawfly, *Athalia lugens proxima* (Klug) on Haliv, *Lepidium sativum*. The investigated results of these studies were summarized and concluded in this chapter.

5.1 Summary

5.1.1 Biology of Mustard Sawfly

The biological parameters of *Athalia lugens proxima* (Klug) were studied under laboratory conditions at room temperature. Observations were recorded daily for incubation duration, larval period, pupal duration, oviposition period, fecundity, adult male and female longevity and sex ratio. Morphometrics readings of different life stages of mustard sawfly was also recorded.

Its mean incubation duration was observed to be 6.95 ± 0.69 days. Eggs average length 0.44 ± 0.01 mm and average width was 0.23 ± 0.01 mm. During larval development, larva passed through six instars. The total larval duration ranged between 9 to 19 days. The mean larval duration found as of 12.65 ± 1.95 days. Full grown larva measured 14.00 ± 1.75 mm in length and 2.55 ± 0.51 mm in width. Pupation takes place in earthen cocoon in soil and pupal period was found varied from 10 to 15 days with mean duration of 12.25 ± 1.37 days. The pupa was 7.70 ± 0.47 mm long and 4.50 ± 0.51 mm broad. Oviposition period ranged from 2 to 7 days with an average 5.95 ± 1.47 days.

Male longevity found more than that of female. Mean longevity of male adult was observed to be 13.5 ± 4.09 days. In female, the longevity was 9.75 ± 3.51 days. Female population are more than population of males. Sex ratio (male adult: female adult) was reported to be 1:2.33. The fecundity varied from 23 to 127 eggs with average number of 74.60 eggs laid by single female. Hatchability of eggs of *Athalia lugens proxima* (Klug) was 86.67 per cent. The average life span of male and female mustard sawfly was observed to be 45.35 ± 6.45 and 41.60 ± 5.69 days, respectively.

5.1.2 Bioefficacy of Biopesticides and Plant Products Against Mustard Sawfly

Results from the present investigation revealed that, all the treatments found effective in reducing the mustard sawfly population when compared with untreated control. Among the all treatments, T_2 *Bt* (*Bacillus thuringiensis*) @ 2 ml/lit.water showed to be the most promising treatment which recorded 1.93 mustard sawfly larvae per plant and statistically found at par with the treatment T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (2.10 mustard sawfly larva per plant), followed by T_4 *Metarhizium anisopliae* 1.15 % WP @ 5g/lit. water (2.43 mustard sawfly larvae per plant), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (2.73 mustard sawfly larvae per plant), T_6 Karanj oil @ 2 ml/lit. water (4.70 mustard sawfly larvae per plant) and T_3 NSE 5 % @ 50 g/lit. water (5.66 mustard sawfly larvae per plant). Whereas, untreated control recorded highest 8.40 mustard sawfly larvae per plant.

From data of per cent reduction in mustard sawfly larval population over pre count after both the sprays, different treatments presented in descending order in reducing larval population as *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water (67.98), *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (64.15), *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (59.82), Azadirachtin 10000 ppm @ 2 ml/lit. water (56.43), Karanj oil @ 2 ml/lit. water (34.63) and NSE 5 % @ 50 g/lit. water (26.68).

5.1.3 Effect of Different Biopesticides and Plant products Against Mustard Sawfly on Seed Yield of Haliv

Results from the present investigation revealed that, all the treatments found effective in achieving higher yield over untreated control. Among all treatments, the highest seed yield 17.49 q/ha was produced by T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water) and it followed by, treatment T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (16.18 q/ha), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (15.42 q/ha), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (14.65 q/ha), T_6 Karanj oil @ 2 ml/lit. water (13.83 q/ha) and T_3 NSE 5 % @ 50 g/lit. water (12.89 q/ha). However, the lowest seed yield (12.07 q /ha) was recorded in the untreated control.

It is reported that, per cent increase in seed yield was highest 44.90 due to application of T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water) and followed by, T_5

Beauveria bassiana 1.15 % WP @ 5 g/lit. water (34.05), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (27.75), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (21.38), T_6 Karanj oil @ 2 ml/lit. water (14.58) and T_3 NSE 5 % @ 50 g/lit. water (6.79).

5.1.4 Incremental Cost Benefit Ratio (ICBR) and B:C Ratio of Different Biopesticides and Plant Products Against Mustard Sawfly

As regards the incremental cost benefit ratio among all treatments, the highest ICBR (1:9.96) was recorded in T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water and it was followed by, T_2 *Bt, Bacillus thuringiensis* @ 2 ml/lit. of water (1:8.85), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit.water (1:7.93), T_1 Azadirachtin 10000 ppm @ 2 ml/lit. water (1:3.69), T_3 NSE 5 % @ 50 g/lit. water (1:1.38), T_6 Karanj oil @ 2 ml/lit. water (1:0.76).

The present investigation revealed that, T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water) with B:C ratio (1:2.26) was highest among all treatments and T_2 treatment followed by T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (1:2.14), T_4 *Metarhizium anisopliae* 1.15 % WP @ 5 g/lit. water (1:2.04), T_1 Azadirachtin 10000 ppm @ 2ml/lit. water (1:1.89), T_3 NSE 5 % @ 50 g/lit. water (1:1.71), T_6 Karanj oil @ 2 ml/lit. water (1:1.69) and T_7 untreated control (1:1.67).

5.2 Conclusions

Following conclusion obtained from the present investigation.

1. The female adult fly of *Athalia lugens proxima* (Klug) laid eggs singly, in slits made with saw like ovipositor along the under sides of the leaf margin. The range of incubation was 6 to 8 days with mean incubation period of 6.95 ± 0.69 days. The mean larval period and pupal period was observed to be, 12.65 ± 1.95 days and 12.25 ± 1.37 days, respectively. Males lived longer than females. The average life span of male and female mustard sawfly was recorded as 45.35 ± 6.45 and 41.60 ± 5.69 days, respectively.
2. From the present investigation, among all treatments, T_2 *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water proved to be the most promising treatment which recorded 1.93 mustard sawfly larvae per plant and it was at par with T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (2.10 mustard sawfly larvae per plant). *Bt (Bacillus thuringiensis)* @ 2 ml/lit. water was the best biopesticide to control

mustard sawfly and it reduced mustard sawfly larval population upto 67.98 per cent.

3. The highest Haliv seed yield (17.49 q/ha) was recorded from the treatment, T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water) and followed by, treatment *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water (16.18 q/ha).
4. The highest incremental cost benefit ratio 1:9.96 was recorded by T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water followed by T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water) with 1:8.85 incremental cost benefit ratio.
5. The highest B:C ratio 1:2.26 was recorded in T_2 *Bt* (*Bacillus thuringiensis* @ 2 ml/lit. of water), followed by T_5 *Beauveria bassiana* 1.15 % WP @ 5 g/lit. water with 1:2.14 B:C ratio.

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7. VITAE

Mr. THIGALE PRAVIN SADASHIV

MASTER OF SCIENCE (AGRICULTURE)

IN

AGRICULTURAL ENTOMOLOGY

2021

Title of Thesis		**:**	"Biology and Ecofriendly Management of Mustard Sawfly, *Athalia lugens proxima* (Klug) on Haliv, *Lepidium sativum*"
Major Field		**:**	Agricultural Entomology
Biographical Information			
Personal	**Date of Birth**	**:**	19th June, 1997
	Place of Birth	**:**	A/P-Shiroli, Tal- Khed, Dist- Pune
	Father's Name	**:**	Shri. Sadashiv Genbhau Thigale
	Mother's Name	**:**	Sau. Surekha Sadashiv Thigale
Educational	**Bachelor Degree Obtained**	**:**	College of Agriculture, Pune
	Class	**:**	First class with distinction
	Name of University	**:**	M.P.K.V., Rahuri, Dist-Ahmednagar, Maharashtra State, India.
Address		**:**	A/P- Pargaon Tarfe Khed, Tal-Ambegaon, Dist- Pune, 410 512.
	Email- id	**:**	pravinthigale4@gmail.com
	Contact Number	**:**	7083983273