

**MONITORING OF INSECTICIDAL RESISTANCE
IN *Leucinodes orbonalis* GUENEE INFESTING
BRINJAL**

**By
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**DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
COLLEGE OF AGRICULTURE, LATUR
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PARBHANI – 431402 (M.S.), INDIA**

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DISSERTATION

**Submitted to
The Vasantnao Naik Marathwada Krishi Vidyapeeth,
Parbhani in partial fulfilment of the requirements for the
Degree of**

**MASTER OF SCIENCE
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**DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
COLLEGE OF AGRICULTURE, LATUR
VASANTRAO NAIK MARATHWADA KRISHI VIDYAPEETH,
PARBHANI**

2019



DEDICATION

Dedicated

To

My Beloved

Parents and Research

Guide

CANDIDATE'S DECLARATION

I

hereby

declare that the

dissertation or part thereof,

has not been previously submitted

by me for a degree of any

University.

Place: Latur
Date: 18 /10/2019

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CERTIFICATE – I

This is to certify that the dissertation entitled
“**MONITORING OF INSECTICIDAL RESISTANCE IN**
Leucinodes orbonalis **GUENEE INFESTING BRINJAL”**
submitted by **DESAI RANJIT UTTAMRAO** Reg. No.
2017A/61ML to the Vasantao Naik Marathwada Krishi
Vidyapeeth, Parbhani in partial fulfilment of the requirements for
the degree of **MASTER OF SCIENCE (Agriculture)** in the
subject of **AGRICULTURAL ENTOMOLOGY** is record of
original and *bonafide* research work carried out by him under my
guidance and supervision. It is of sufficiently high standard to
warrant its presentation for the award of the said degree.

I also certify that the dissertation or part thereof has
not been previously submitted by him for a degree of any
university.

Place: Latur
Date: 18/10/2019

(Dr. V.K. Bhamare)
Research Guide
and
Chairman,
Advisory Committee

CERTIFICATE – II

This is to certify that the dissertation entitled “**MONITORING OF INSECTICIDAL RESISTANCE IN *Leucinodes orbonalis* GUENEE INFESTING BRINJAL**” submitted by **DESAI RANJIT UTTAMRAO** Reg. No. **2017A/61ML** to the Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (Agriculture)** in the subject of **AGRICULTURAL ENTOMOLOGY** has been approved by the student’s advisory committee after viva-voce examination in collaboration with the external examiner.

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“Native ability without education is like a tree without fruit”

To reach a goal, you don't need to know all the answers in advance. But you must have clear idea of the goal you want to reach. Success is possible only after involvement of many minds and hands. Emotions can not be expressed in words because then emotions are transformed into mere formalities. Nevertheless, formalities have to be completed.

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Place: Latur

Date: 18.10.2019

(Desai Ranjit Uttamrao)

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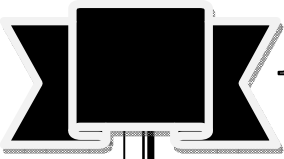
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ABBREVIATIONS

°C	-	Degree celcius
<i>et al.</i>	-	<i>et alia</i> , and others
Fig.	-	Figure
FL	-	Fiducial limit
g	-	Gram (s)
i.e.	-	<i>Id est</i> , that is
LC ₅₀	-	Lethal concentration which kill 50% population
LC ₉₀	-	Lethal concentration which kill 90% population
LDP	-	Log dose probit
lit	-	litre (s)
LL	-	Lower limit
m	-	Meter
mg	-	Miligram
ml	-	Mililitre (s)
no.	-	Number (s)
RR	-	Resistance ratio
RF	-	Resistance factor
S.E.	-	Standard error
UL	-	Upper limit
<i>viz.</i> ,	-	Videlicet, namely
%	-	Per cent
a.i.	-	Active ingredient
x^2	-	Chi-square



INTRODUCTION

Chapter I

INTRODUCTION

Solanum melongena L. (Solanaceae) is an important vegetable crop commonly known as brinjal or eggplant or aubergine, a nightshade species that is grown for its edible fruits. Brinjal is the most common, popular and widely cultivated vegetable crop in both tropical and sub-tropical parts of the world. India is the centre of origin for Brinjal. It is known as poor man's vegetable or king of vegetables because nutritionally per 100 g of raw eggplant contains water (92.30 g), carbohydrates (5.88 g), protein (0.98 g), fat (0.18 g), fiber (3.0 g), calories (35 kcal), cholesterol (0 mg), potassium (229 mg), phosphorous (24 mg), magnesium (14 mg), calcium (9 mg), vitamin A (23 IU), B-6 vitamins (0.084 mg), vitamin C (2.2 mg), vitamin E (0.30 mg), vitamin K (3.5 µg) and folate (22 µg) (USDA, 2019). It is rich in anthocyanins and antioxidants which have potential health effects against cancer, aging, inflammation and neurological diseases.

Globally, brinjal was cultivated on 1.85 million hectares of area with 52.31 million tonnes of production and 28.14 tonnes per ha of productivity during 2017. China contributed to 62.86 per cent of this output while India accounted for 23.92 per cent of the production during 2017. It is one of the most important vegetables in Asia, where more than 93.8 per cent of the world's brinjal production occurs. The other major brinjal producing countries are Egypt, Turkey, Iran, Indonesia, Iraq, Japan, Italy, Philippines, Bangladesh, Sudan, Thailand, Romania, Pakistan, Syria, Azerbaijan, Algeria, Greece, Kazakhstan, United States, Venezuela and France (FAOSTAT, 2019).

India is the second largest producer of vegetables and brinjal in the world after China. After potato, it ranked second highest consumed vegetable in India, along with tomato and onion (Anonymous, 2017). In India brinjal was grown on about 0.730 million hectares of land with an annual production of 12.80 million tonnes and productivity of nearly 17.53 tonnes per ha during 2017-18 (AGRISTAT, 2019). The major brinjal producing states in India are West Bengal, Orissa, Jharkhand, Gujarat, Madhya Pradesh, Bihar, Chhattisgarh, Karnataka, Andhra Pradesh, Maharashtra, Haryana, Uttar Pradesh, Assam, Tamil Nadu and Telangana (AGRISTAT, 2019). The Maharashtra is accounted 22.48 thousand hectares of land for brinjal cultivation with 429.91 thousand tonnes of production and productivity of nearly 19.12 tonnes per ha during 2017-18 (AGRISTAT, 2019).

In India several biotic and abiotic factors are responsible for lowering brinjal yield. Among various biotic factors, insect-pests are important which greatly affect the quality and productivity of brinjal through inflicting a direct damage. The brinjal is attacked by about 140 species of insect-pests (Dwivedi *et al.*, 2014), amongst them, *Leucinodes orbonalis* (Guenee) is key pest and alone reportedly caused yield loss ranging from 11.10 to 92.50 per cent in different parts of India (Singh *et al.*, 2014). The pest remains active throughout the year, except for few months during winter season.

The management of *L. orbonalis* is too difficult because the larvae lie inside the shoot or fruit and the insecticide could not reach the pest directly (Alam *et al.*, 2003). In India and other South East Asian countries brinjal growers rely exclusively on application of insecticides to combat *L. orbonalis*. Farmers spray chemical insecticides, 15-40 times in India, 56 times in Philippines and 180 times in Bangladesh on brinjal

crop during a cropping season (Srinivasan, 2008). The consecutive, excessive and indiscriminate use of chemical insecticide is causing multiple side effects that include exposure of farm labourers and consumers to pesticide residue, increased costs of production, environmental pollution, destruction of natural enemies of pests, resurgence of pest population and development of pesticide resistance in *L. orbonalis* (Shirale *et al.*, 2017; Mathur *et al.*, 2012; Harish *et al.*, 2011 and Natekar *et al.*, 1987).

Insecticide resistance is a result of accelerated microevolution. It results from the survival and spread of resistant insect genotypes that have the capability to endure insecticide selection pressures in the environment. Development of resistance in insects to insecticides is an inevitable consequence of insecticide use for pest control (IRAC, 2005). In India, Central Insecticide Board and Registration Committee recommended several insecticides against *L. orbonalis*. However, repeated application of these insecticides results in reduction of sensitivity in *L. orbonalis*. Hence, periodic monitoring of insecticidal resistance in *L. orbonalis* is highly essential so as to alert growers about changes in resistant populations, development of novel resistance and helping them in taking correct pest control decisions.

Keeping this in view, the present investigation was framed to monitor the levels of insecticidal resistance in the field population of *L. orbonalis* infesting brinjal grown in different districts of Western Maharashtra region during 2018-19 with following objective.

1. To monitor the levels of insecticidal resistance in *Leucinodes orbonalis* Guenee infesting brinjal.



REVIEW OF LITERATURE

Chapter II

REVIEW OF LITERATURE

The pertinent literature on monitoring of insecticidal resistance in *Leucinodes orbonalis* Guenee infesting brinjal has been reviewed under the following heads.

2.1 Insecticidal resistance in *Leucinodes orbonalis* Guenee infesting brinjal

2.2 Insecticidal resistance in different Lepidopteran insect-pests

2.1 Insecticidal resistance in *Leucinodes orbonalis* Guenee infesting brinjal

Rahman and Rahman (2009) investigated development of insecticidal resistance in *L. orbonalis* populations collected from Jessore and Gazipur districts of Bangladesh with different bioassay methods and revealed that the leaf round method was best in estimating the toxicity of carbosulfan 20 EC (Marshal), cypermethrin 10 EC (Ripcord) and cypermethrin 10 EC (Basathrin) considering the variation of mortality estimates, control mortality, the lowest LC₅₀ value and the lowest χ^2 value. The concentrations 0.1 were selected discrimination of concentration (DC) of Marshal 20 EC, Ripcord 10 EC and Basathrin 10 EC. The observed mortalities in those concentrations were 73.33 and 80.00; 73.33 and 73.33 and; 73.33 and 80.00 per cent, respectively for Marshal, Ripcord and Basathrin in Jessore and Gazipur districts. The percentage of resistance was higher (18.19 per cent) to carbosulfan 20 EC in Jessore population of *L. orbonalis* than in Gazipur (11.52 per cent).

Kavuri Yogi and Ashwani Kumar (2010) evaluated efficacy of different insecticides against *L. orbonalis* under laboratory conditions

and evidenced that the mortality of 3rd instar *L. orbonalis* larvae was varied from 52.87-81.78 per cent in emamectin benzoate, chlorfenapyr and novaluron on 3rd day. Observations on 5th and 7th day indicated a greater per cent kill of the larvae and treatments indoxacarb, spinosad and neem had not given expected kill. The larval mortality was noticed to the extent of 88.83, 92.52 and 94.34 per cent in the treatments of novaluron, emamectin benzoate and chlorfenapyr, respectively on 10th day. In all other treatments the larval mortality varied from 85.36 to 71.82 per cent over untreated control.

Latif *et al.* (2010) studied toxicity of nine insecticides *viz.*, azadirachtin 0.03 EC, abamectin 1.8 EC, flubendiamide 24 WG, chlorpyrifos 20 EC, cartap 50 SP, carbosulfan 20 EC, thiodicarb 75 WP, cypermethrin 10 EC and lambda-cyhalothrin 2.5 EC belonging to different chemical groups against *L. orbonalis* and revealed that carbosulfan and flubendiamide exhibited highest toxicity against fourth instar larvae of *L. orbonalis* after 24 and 48 h of exposure in laboratory trial.

Saimandir and Gopal (2012) investigated toxicity and persistence pattern of thiacloprid against *L. orbonalis* and indicated that thiacloprid at the experimented doses (30 and 60 g ai per ha) was found to be ineffective against *L. orbonalis* and reported unsafe for human consumption after a waiting period of 3 days as it left high residues on the fruits.

Shirale *et al.* (2012) evaluated efficacy of chlorantraniliprole 18.50% SC (Coragen), flubendiamide 39.35% SC (Fame), indoxacarb 14.50% SC (Avaunt), chlorfenapyr 10% SC (Intrepid) and spinosad 45% SC (Spintor) against *L. orbonalis* and evidenced that chlorantraniliprole

18.50% SC and flubendiamide 39.35% SC were found superior over other insecticides against *L. orbonalis*.

Anonymous (2013) studied insecticide resistance in *L. orbonalis* populations collected from Bangalore, Guntur, Dharmapuri and Coimbatore against three insecticides with the filter paper residue assay and revealed up to six fold variation in susceptibility with respect to fenvalerate, phosalone and emamectin benzoate in the populations of *L. orbonalis* tested. Quantification of midgut carboxylesterase from these four populations of *L. orbonalis* indicated significantly elevated activity of carboxylesterase in larvae collected from Guntur region.

Kodandaram *et al.* (2013) investigated baseline toxicity of diamide insecticides against *L. orbonalis* and noticed that the LC₅₀ values of *L. orbonalis* to cyantraniliprole, chlorantraniliprole and flubendiamide were 0.000062 per cent (0.62 ppm), 0.00018 per cent (1.8 ppm) and 0.00112 per cent (11.2 ppm), respectively. The descending order of toxicity for *L. orbonalis* was cyantraniliprole > chlorantraniliprole > flubendiamide. The results of relative toxicity revealed that cyantraniliprole and chlorantraniliprole was 18 and 6.2 times more toxic to *L. orbonalis* as compared to flubendiamide. Among different diamide insecticides, the new molecule cyantraniliprole 10% OD was found to be highly effective against *L. orbonalis*.

Botre *et al.* (2014) evaluated insecticide resistance in *L. orbonalis* collected from different locations of Vidarbha region of Maharashtra to five insecticides and exhibited that the LC₅₀ values for field strain to rynaxypyr, flubendiamide, emamectin benzoate, indoxacarb and spinosad found in the range of 0.127 to 0.157, 15.551 to 23.046, 0.277 to 0.351, 2.016 to 2.457 and 3.094 to 4.940 ppm, respectively.

Akola, Amravati and Yavatmal strains showed high level of insecticide resistance than Buldhana and Washim strains of *L. orbonalis*. Rynaxypyr 20 SC and emamectin benzoate 5 SG were found most effective amongst the insecticides tested. The LC₅₀ values of susceptible strain were 0.104, 9.080, 0.214, 0.867 and 1.523 ppm for rynaxypyr, flubendiamide, emamectin benzoate, indoxacarb and spinosad, respectively. Thus, rynaxypyr and emamectin benzoate could be used to delay the development of insecticide resistance.

Das and Islam (2014) studied different concentrations of buprofezin 40 SC against 2nd instars larvae of *L. orbonalis* through topical, potato-dip and topical + potato-dip method of application and reported that the significant level of mortality and weight reduction was observed at 3 days after treatment from all applying methods but the maximum mortality and weight reduction was found at 7 days after treatment. It was also observed that potato-dip method was highly effective than topical method in recording mortality and weight reduction while almost similar efficacy was found from potato-dip and combination (topical + potato-dip) methods. Cuticular abnormalities were found when larvae were treated with higher concentrations of buprofezin in comparison with that in the water-treated control. Moreover, larval mortality and weight reduction were clearly dose-dependent. The lower dose (200 ppm) was ineffective for topical application method but was effective in case of potato-dip and combination methods.

Kaur *et al.* (2014) investigated baseline susceptibility of *L. orbonalis* collected from three different locations *viz.*, Amritsar, Malerkotla and Hoshiarpur of Punjab state to novel insecticides and bio-pesticide and revealed that LC₅₀ values obtained for different locations varied between 0.061-1.6 ppm. The LC₅₀ values of emamectin benzoate,

chlorantraniliprole, indoxacarb, spinosad and delfin against Amritsar, Malerkotla and Hoshiarpur population were 0.49, 0.74, 0.87, 1.6 and 0.88 ppm; 0.061, 0.092, 0.12, 0.41 and 0.11 ppm and; 0.24, 0.38, 0.23, 0.81 and 0.46 ppm, respectively. Emamectin benzoate showed highest toxicity against *L. orbonalis* for Amritsar and Malerkotla populations with LC₅₀ values of 0.49 and 0.061 ppm, respectively followed by chlorantraniliprole, indoxacarb, delfin and spinosad. However, in Hoshiarpur population there was not any appreciable difference between the LC₅₀ values of emamectin benzoate and indoxacarb. The toxicity ratios of emamectin benzoate for Amritsar, Malerkotla and Hoshiarpur populations were 3.26, 6.72 and 3.37-fold, respectively.

Ranjith Kumar (2014) investigated baseline susceptibility of *L. orbonalis* to different group of insecticides and revealed that among insecticides, highest level of resistance development was noticed against chlorpyrifos and endosulfan in fourteen geographic populations. Among the insecticides, the highest resistance ratio was recorded in Raichur and lowest in Margoa populations. Among the populations, Raichur population showed a maximum LC₅₀ values (2.15 and 2.30 ppm) and higher degree of resistance (1.30 and 1.35-fold) to rynaxypyr during 2009-10 and 2010-11. However, Bangalore population noticed a maximum LC₅₀ values (4.20 and 4.41 ppm) and higher degrees of resistance (1.95 and 1.97-fold) to emamectin Benzoate during 2009-10 and 2010-11. The data revealed that Raichur population (42.00 ppm and 1.20-fold during 2009-10) and Hyderabad population (58.60 ppm and 1.33-fold during 2010-11) recorded a maximum LC₅₀ value and resistance ratio to cypermethrin. The data revealed that Bangalore population recorded a maximum LC₅₀ value (240.00 and 249.83 ppm

during 2009-10 and 2010-11, respectively) and resistance ratio (1.20- and 1.18-fold during 2009-10 and 2010-11, respectively) to chlorpyrifos.

Kodandaram *et al.* (2015) evaluated dose mortality response of different insecticides against *L. orbonalis* and exhibited that cyantraniliprole was most toxic to third instar larvae of *L. orbonalis*. The LC₅₀ values for cyantraniliprole, chlorantraniliprole, flubendiamide and cypermethrin were 0.62, 1.8, 11.2 and 4057 ppm, respectively. The descending order of toxicity for was cyantraniliprole > chlorantraniliprole > flubendiamide > cypermethrin. On the basis of LC₅₀ values, cyantraniliprole, chlorantraniliprole, flubendiamide were 6543.54, 2253.88 and 362.23 times more toxic to *L. orbonalis* as compared to cypermethrin. The results clearly indicated that the new anthranilic diamide insecticide, cyantraniliprole was highly toxic to the larvae of *L. orbonalis* as compared to other diamide insecticides and cypermethrin. Cyantraniliprole when applied as fruit dip, was 6543 times more toxic to *L. orbonalis* as compared to cypermethrin. The descending order of toxicity of tested insecticides was cyantraniliprole > chlorantraniliprole > flubendiamide > cypermethrin. Under laboratory bioassays the third instar larvae of *L. orbonalis* were found more susceptible to cyantraniliprole at the rate of 90 g a.i. per ha and recorded highest per cent mortality of 91.66 and 99.00 at 24 and 48 hrs after treatment, respectively. Chlorantraniliprole was next best treatment with 82.00 and 100 per cent mortality, whereas conventional insecticide cypermethrin, belonging to synthetic pyrethroid group, exhibited only 52.33 and 66.66 per cent mortality at 24 and 48 hrs after treatment, respectively. Mortality of *L. orbonalis* was dose dependent and highest mortality percentage was recorded in cyantraniliprole 90 g a.i. ha after 24 and 48 hrs after treatment. The data indicated that among different diamide insecticides,

cyantraniliprole at the rate of 90-105 g a.i. per ha proved to be highly effective against *L. orbonalis*. The data also indicated lower efficacy of conventional insecticides viz., dimethoate and profenophos.

Munje *et al.* (2015) evaluated LC₅₀ values of newer insecticide viz., rynaxypyr 20 SC, flubendiamide 480 SC, emamectin benzoate 5 SG, indoxacarb 14.5 SC and spinosad 45 SC against *L. orbonalis* collected from different location of Vidarbha viz., Akola, Amravati, Yavatmal, Washim and Buldhana by using direct spray method during 2011-12 and revealed that the resultant toxicity in terms of LC₅₀ values ranged for rynaxypyr (0.127-0.157 ppm), flubendiamide (15.551-23.046 ppm), emamectin benzoate (0.277-0.351 ppm), indoxacarb (2.016-2.457 ppm) and spinosad (3.094-4.940 ppm). Rynaxypyr 20 EC and emamectin benzoate 5 SG were found most effective amongst the insecticides tested. Thus, rynaxypyr and emamectin benzoate could be used for management of *L. orbonalis* and to delay the development of insecticide resistance.

Kodandaram *et al.* (2017) studied susceptibility of *L. orbonalis* to three diamide insecticides by fruit dip bioassay technique and exhibited that cyantraniliprole and chlorantraniliprole were 5.23 and 2.80 times more toxic to *L. orbonalis* as compared to flubendiamide. Large variation in the susceptibility of *L. orbonalis* to cyantraniliprole, chlorantraniliprole, flubendiamide was observed and the LC₅₀ values were 0.084, 0.157 and 0.439 mg a.i. per l, respectively. In span of two years there was a significant increase in the LC₅₀ values of cyantraniliprole (0.062 to 0.085 mg a.i. per l), chlorantraniliprole (0.097 to 0.157 mg a.i. per l), flubendiamide (0.284 to 0.439 mg a.i. per l) to population of *L. orbonalis*, which showed 1.35, 1.62 and 1.55-fold

resistance, respectively indicated faster development of resistance to diamide insecticides.

Murali *et al.* (2017) studied development of resistance in different populations of *L. orbonalis* to six different pyrethroids and reported that the Kolar population was found most susceptible to alphamethrin, deltamethrin and λ -cyhalothrin with LC₅₀ values of 0.01, 0.02 and 0.02 ml per *l*, respectively, while Belagavi and Bengaluru and Koppal population were recorded most susceptible to cypermethrin, fenvalerate and fenpropathrin, LC₅₀ values ranged from 0.04 to 0.13 ml per *l*. The results also suggested different pyrethroids use pattern in different places, among different populations, Koppal population was found 24-fold resistant to alphamethrin, Belagavi population was 12-fold resistant to deltamethrin, Bengaluru population was 10.5-fold resistant to λ -cyhalothrin and Belagavi population was 2.5-fold more resistant to fenpropathrin. However, all populations were found to be highly susceptible to cypermethrin and highly resistant to fenvalerate as LC₅₀ values ranged from 0.13 to 0.26 ml per *l* for different populations.

Shirale *et al.* (2017) investigated six commonly used insecticides *viz.*, carbaryl, chlorpyrifos, deltamethrin, endosulfan, fenvalerate and profenofos against *L. orbonalis* larvae and revealed that the *L. orbonalis* populations exhibited widespread resistance to tested insecticides. The highest average resistance ratio (RR) in the two-year study was observed in the assays of populations with deltamethrin (21.50-82.42-fold) followed by assays conducted with endosulfan (24.47-68.26-fold), chlorpyrifos (22.17-63.14-fold), carbaryl (39.18-49.09-fold) and fenvalerate (14.00-44.66-fold); and the lowest average RRs were observed in the assays with profenofos (16.65–39.43-fold). The high

levels of LD₅₀ values could be attributed to the long-term indiscriminate use of these insecticides in eggplant growing regions.

Kate (2018) investigated insecticidal resistance in *L. orbonalis* population collected from different locations of Marathwada region of Maharashtra, India and reported that the *L. orbonalis* population collected from Hingoli recorded 5.80-fold resistance to dimethoate 30% EC which was highest among the insecticides tested. The resistance ratios varied greatly among the populations of *L. orbonalis* viz., dimethoate 30% EC (4.80- to 5.80-fold), chlorpyrifos 20% EC (4.2- to 5.4-fold), lambda-cyhalothrin 5% SC (3.55- to 4.21-fold), cypermethrin 25% EC (3.18- to 3.72-fold), fenpropathrin 30% EC (2.51- to 3.00-fold), emamectin benzoate 5% SG (2.33- to 2.75-fold), chlorantraniliprole 18.5% SC (2.00- to 2.42-fold), thiacloprid 21.7% SC (1.56- to 1.83-fold) and cyantraniliprole 10.26% OD (1.24- to 1.42-fold). The resistance factor of cyantraniliprole 10.26% OD, chlorantraniliprole 18.5% SC, emamectin benzoate 5% SG, fenpropathrin 30% EC and thiacloprid 21.7% SC against all the field populations of *L. orbonalis* exhibited susceptibility while, the resistance factor of dimethoate 30% EC, chlorpyrifos 20% EC, lambda-cyhalothrin 5% SC and cypermethrin 25% EC indicated decreased susceptibility to development of low level of resistance.

Sharma *et al.* (2018) studied residual toxicity of different insecticides against *L. orbonalis* at Palampur and reported that the Persistent Toxicity (PT) values of chlorantraniliprole 0.007 per cent, cyantraniliprole 0.012 per cent, thiacloprid 0.03 per cent, lambda-cyhalothrin 0.004 per cent and indoxacarb 0.01 per cent were found to be 449.16, 414.17, 379.17, 355.83 and 297.48, respectively and the corresponding LT₅₀ values were 5.16, 4.47, 3.83, 3.35 and 2.41 days

during 2015, respectively. However, the Persistent Toxicity (PT) values of chlorantraniliprole 0.007 per cent, cyantraniliprole 0.012 per cent, thiacloprid 0.03 per cent, lambda-cyhalothrin 0.004 per cent and indoxacarb 0.01 per cent were 437.5, 425.83, 379.16, 344.17 and 309.16, respectively and the corresponding LT_{50} values were 4.99, 4.69, 3.77, 3.19 and 2.61 days during 2016, respectively. On the basis of average PT values, the order of toxicity was chlorantraniliprole > cyantraniliprole > thiacloprid > lambda-cyhalothrin > indoxacarb against neonates of *L. orbonalis*.

2.2 Insecticidal resistance in different Lepidopteran insect-pests

Saini *et al.* (1989) investigated development of insecticidal resistance and cross resistance in fenvalerate and cypermethrin selected strains of *Earias vittella* (Fab.) and reported that when first-instar *E. vittella* larvae were selected with fenvalerate and cypermethrin for 15 successive generations in the laboratory at 28°C developed 78-fold resistance to fenvalerate and no resistance to cypermethrin. The fenvalerate selected strain developed 2800-fold and 1200-fold cross-resistance to endosulfan and carbaryl, respectively. This strain did not manifest cross-resistance to the organophosphorus insecticides such as quinalphos, fenitrothion, monocrotophos and malathion, or to the synthetic pyrethroid, cypermethrin. The cypermethrin-selected strain acquired 5-, 4- and 3-fold cross-resistance to endosulfan, fenvalerate and carbaryl, respectively and no cross-resistance to the above organophosphorus insecticides.

Satpute *et al.* (2003) monitored insecticide resistance in *E. vittella* collected from different locations of Western Vidarbha Region of India and revealed that the Akola strain was comparatively more resistant to all the insecticides tested except quinalphos when compared with

Amravati, Washim and Nagpur strains. It was 3.63 and 6.05-fold resistant against endosulfan, 20.96 and 39.69-fold resistant against cypermethrin and; 5.29 and 7.81-fold resistant against thiodicarb during 2000-01 and 2001-02, respectively. However, Washim strain was found to be more resistant to quinalphos (7.55 and 12.66-fold during 2000-01 and 2001-02, respectively) than other strains. Moreover, *E. vittella* population from all the locations was highly resistant to cypermethrin than other three insecticides tested.

Deepa *et al.* (2006) evaluated acute toxicity of lambda-cyhalothrin 5.0 CS against *E. vittella* and illustrated that the median lethal dose (LD₅₀) of lambda-cyhalothrin for F₁ population of *E. vittella* was 0.00394 µg per larva and LD₉₅ value was 0.0174 µg per larva. The LD₅₀ value of F₇ generation was 0.00267 µg per larva and LD₉₅ was 0.0142 µg per larva. The susceptibility increased up to seven generations of insecticide exposure free culturing as evidenced from decline in LC₅₀ and LC₉₅ values. The susceptibility index (SI) of F₇ generation over F₁ was 1.4757 based on LD₅₀ and 1.2185 based on LD₉₅. The rate of resistance decline (R) was -0.0241. The number of generations required for a 10-fold decrease in LC₅₀ was calculated as 41.49. Based on LD₉₅ of F₁ generation the tentative discriminating dose (DD) arrived was 0.017 µg per larva.

Ahmad *et al.* (2007) evaluated field populations of *S. litura* from Pakistan for their resistance to conventional insecticidal chemistries during 1997–2005 using a leaf dip bioassay method and revealed that resistance levels were very low to low to endosulfan, chlorpyrifos, phoxim, quinalphos, profenofos, bifenthrin and thiodicarb and; moderate to high to methomyl and cyfluthrin. Correlation analysis indicated that insecticides belonging to the same class such as organophosphate,

carbamate or pyrethroid exhibited a positive cross resistance in *S. litura*. Positive correlation was also found between endosulfan and carbamates. Except methomyl and bifenthrin, which were negatively correlated, there was no cross resistance between organophosphate or carbamate or pyrethroid insecticides in the resistant populations of *S. litura*.

Ahmad and Arif (2008) monitored field populations of *E. vittella* at Multan in Pakistan, from 1999 to 2007 for their resistance against six pyrethroid, four organophosphorus and six new chemical insecticides using a leaf-dip bioassay and revealed that of the pyrethroids, resistance was generally low to zeta-cypermethrin and moderate to high or very high to cypermethrin, deltamethrin, esfenvalerate, bifenthrin and lambda-cyhalothrin. Resistance to organophosphates viz., chlorpyrifos, profenofos, triazophos and phoxim was recorded at very low to low levels. Among new chemicals, *E. vittella* had no or a very low resistance to spinosad, emamectin benzoate and methoxyfenozide, a very low to low resistance to abamectin, a very low to moderate resistance to indoxacarb and a moderate resistance to chlorfenpyr. The results indicated lack of cross resistance between pyrethroids and organophosphorus insecticides in *E. vittella*. Rotation of insecticides showed no, very low or low resistance, but belonging to different insecticides classes with unrelated modes of action, might prevent or mitigate insecticide resistance in *E. vittella*.

Saleem *et al.* (2008) investigated toxicity of most commonly used insecticides of organochlorine, organophosphate and carbamate groups against *S. litura* populations collected for three consecutive years (2004-2006) and revealed that the resistance ratios in populations when compared with Lab-PK were in the range of 10- to 100-fold for endosulfan, 5- to 111-fold for cypermethrin, 2- to 98-fold for

deltamethrin, and 7- to 86-fold for betacyfluthrin. For organophosphates and carbamates, resistance ratios were in the range of 3- to 9-fold for profenophos, 18- to 421-fold for chlorpyrifos, 3- to 160-fold for quinalphos, 6- to 126-fold for phoxim, 7- to 463-fold for triazophos, 10- to 389-fold for methomyl and 16- to 200-fold for thiodicarb.

Ishtiaq and Saleem (2011) tested two field populations of *S. exigua* from Dera Ghazi Khan (D. G. Khan) and Multan, Pakistan for resistance to the 10 most commonly used insecticides in Pakistan and revealed that the population of *S. exigua* from Multan showed very low level of resistance to two pyrethroids, i.e., deltamethrin (RF=5) and cypermethrin (RF=6), whereas the D.G. Khan population of *S. exigua* was moderately resistant to deltamethrin (RF=33) and very highly resistant to cypermethrin (RF=132). The results of toxicity of organophosphates to the Multan population showed a very low level of resistance to chlorpyrifos (RF=8) and a high level of resistance to profenofos (RF=86), whereas the D.G. Khan population was highly resistant to chlorpyrifos (RF=62) and very highly resistant to profenofos (RF=126). New chemistry insecticides showed variable levels of resistance in both the populations. Emamectin benzoate was highly toxic among all the insecticides tested. It resulted in a very low level of resistance in the population collected from both Multan (RF=4) and D.G. Khan (RF =8). Emamectin benzoate and lufenuron were found to be more toxic than other insecticides against both populations, with low to very low levels of resistance.

Ishtiaq *et al.* (2012a) detected development of insecticide resistance in field population of *S. exigua* from Lodhran and found that *S. exigua* were resistant to conventional insecticides and registered 65, 66, 92, 73, 34 and 29-fold resistance to deltamethrin, cypermethrin,

chlorpyrifos, profenofos, abamectin and spinosad, respectively, compared with Lab-PK susceptible population. Field population was divided into two sub-populations. One was left unselected and the second (Del-SEL) selected for five generations at the dose equal to LC_{50} . Bioassays at G_5 for Del-SEL strain gave resistance ratios of 976, 421, 118, 30, 15 and 17-fold for deltamethrin, cypermethrin, chlorpyrifos, profenofos, abamectin and spinosad, respectively compared with Lab-PK. Resistance was found stable for all the insecticides in the field population but it was more stable in Del-SEL strain for deltamethrin, cypermethrin and chlorpyrifos than profenofos, abamectin and spinosad when reared without exposing to deltamethrin (G_5 - G_{10}). It indicated that cross resistance occurred between deltamethrin, cypermethrin and chlorpyrifos. There was no effect of delta selection on the toxicity of three insecticides i.e. profenofos, abamectin and spinosad, which indicated lack of cross resistance with deltamethrin.

Ishtiaq *et al.* (2012b) studied the resistance in Pakistani populations of *S. exigua* collected from four districts of Punjab to various insecticides from 2008-2010 using a standard leaf dip bioassay method and indicated that resistance ratios compared with a susceptible Lab-PK population were in the range of 7-105-fold for deltamethrin, 12-136-fold for cypermethrin, 20-134-fold for chlorpyrifos, 37-143-fold for profenofos, 3-73-fold for spinosad, 5-226-fold for abamectin, 6-88-fold for indoxacarb, 3-75-fold for emamectin benzoate, 2.4-59-fold for lufenuron and 3-41-fold for methoxyfenozide. The pair wise correlation coefficients of LC_{50} values indicated a positive correlation with cross-resistance among deltamethrin, cypermethrin and chlorpyrifos, whereas resistance to profenofos showed correlations with resistances to other insecticides except chlorpyrifos. The new chemistry insecticides showed no correlations among any of the tested insecticides. There were high to

very high levels of resistance to organophosphates in most of the populations, which suggested that these should be avoided against this pest.

Kang *et al.* (2012) determined the toxicity of different insecticides against third instar larvae of *E. vittella* populations collected from different locations of Punjab and revealed that based on the LD₅₀ values obtained for different insecticides, flubendiamide was found to be most toxic against all the populations with LD₅₀ values ranging from 0.004 to 0.010 µg per larvae followed by profenophos except against Mansa population where toxicity of deltamethrin (0.018 µg per larvae) was more than profenophos (0.033 µg per larvae). Cypermethrin was found to be least effective against Mansa and Muktsar populations with LD₅₀ values 0.325 and 0.173 µg per larvae, respectively and endosulfan to Ludhiana population with LD₅₀ value (0.126 µg per larvae).

Verma *et al.* (2012) exposed first-instar *E. vittella* larvae to different concentration of indoxacarb for 15 successive generations in the laboratory at 28±1°C to develop the selected strain and indicated that *E. vittella* developed 3.07-fold resistance to indoxacarb. Studies on cross-resistance indicated that the indoxacarb-selected strain developed low level of cross resistance for endosulfan (3.60-fold), cypermethrin (3.13-fold) and chlorpyrifos (3.05-fold). The strain, however, did not manifest cross-resistance to other organophosphorus insecticides (quinalphos and monocrotophos), synthetic pyrethroids (fenvalerate), carbamate (carbaryl) and ready-mix formulation of chlorpyrifos + cypermethrin.

Aruna Sri *et al.* (2014) studied status of insecticide resistance in *S. litura* infesting cotton in Guntur and Prakasam districts of Andhra Pradesh and revealed that Guntur population of *S. litura*

developed 6.3 and 5.4; 3.0 and 2.9; 1.7 and 1.4; 16.2 and 14.4; 1.14 and 1.11-folds resistance at LD₅₀ and 11.3 and 7.06; 4.2 and 3.2; 1.07 and 1.06; 34.8 and 26.9; 3.5 and 2.9-folds resistance at LD₉₀ level to chlorpyrifos, quinalphos, endosulfan, cypermethrin and methomyl during *Kharif* 2007 and 2008, respectively. However, the corresponding values for Prakasam population of *S. litura* were 5.7 and 2.6; 1.7 and 1.7; 1.4 and 1.3; 15.4 and 11.3; 1.11 and 1.03-folds at LD₅₀, and 8.6 and 3.7; 1.9 and 1.19; 1.05 and 1.04; 30.9 and 25.6; 3.1 and 2.6-folds resistance at LD₉₀, respectively.

Hussain *et al.* (2014) studied toxicity of some new insecticides against *H. armigera* collected from three different locations of Punjab (Pakistan) for three consecutive years and showed that the toxicity or resistant ratio of profenofos compared with the Lab-Pk strain was in the range of the 9.80-12.11-fold, 1.69-5.22-fold for emamectin benzoate, 19.6-68.17-fold for lambda-cyhalothrin, 3.48-9.62-fold for chlorpyrifos, 34.1-48.0-fold for bifenthrin, 19.33-37.17-fold for deltamethrin and 5.60-11.50-fold for thiodicarb. The Resistance Ratio of the Insect Growth Regulator (IGR) was in the range of 5.98-11.83-fold for the methoxyfenozide and 1.01-2.19-fold for lufenuron. Pair wise comparison of the log LC₅₀ of insecticides against all populations showed a correlation between the various insecticides, suggested that cross resistance was occurred. When these same insecticides were tested for susceptible population (Lab-Pk), emamectin benzoate and lufenuron were significantly more toxic than other tested insecticides.

Ishtiaq *et al.* (2014) studied stability and cross resistance to emamectin benzoate in a preselected population of beet armyworm and exhibited that bioassays at G₁ for the field population, recorded resistance ratios (RRs) of 220, 149 and 38-fold for emamectin benzoate, spinosad

and lufenuron, respectively, compared with a susceptible laboratory population (Lab-PK). Resistance ratios were increased by 526-fold and 6-fold compared with Lab-PK and the unselected field population (Ema-UNSEL, G₆), respectively after selection with emamectin benzoate (Ema-SEL) for five generations (G₆). Selection with emamectin benzoate had no apparent effect on susceptibility of Ema-SEL to spinosad and lufenuron, instead toxicity to the latter insecticides reduced, suggested there was no cross-resistance between these compounds. Lack of cross-resistance and the apparent instability of resistance to emamectin benzoate suggested that spinosad and lufenuron were suitable alternatives for use with emamectin benzoate in resistance management.

Bird (2015) determined the baseline susceptibility of *H. armigera* to emamectin benzoate, chlorantraniliprole and indoxacarb in feeding assays on insecticide-incorporated artificial diet under laboratory conditions and revealed that emamectin benzoate had the highest toxicity with a median lethal concentration (LC₅₀) of 0.01 µg per ml diet (n=20 strains). The LC₅₀ for chlorantraniliprole was 0.03 µg per ml diet (n=21 strains), while indoxacarb had the lowest relative toxicity with an average LC₅₀ of 0.3 µg per ml diet (n=22 strains). Variation in susceptibility amongst field strains was 2.3-fold for emamectin benzoate and 2.9-fold for chlorantraniliprole and indoxacarb. Discriminating concentrations of 0.2, 1 and 12 µg of insecticide per milliliter of diet for emamectin benzoate, chlorantraniliprole and indoxacarb, respectively, were calculated from toxicological data from field *H. armigera* strains, as a first step in resistance management of these classes of insecticide in Australia.

Deepa (2015) evaluated the resistance pattern of *H. armigera* to certain new insecticide molecules and revealed that larval population

collected from Mahaboobnagar recorded the LC₅₀ and LC₉₀ values at 24, 48 and 72 hours after treatment for different chemicals viz., flubendiamide, (0.1 and 2.2, 0.2 and 3.5 and; 0.4 and 4.2 mg/l, respectively), indoxacarb (0.2 and 3.5, 0.3 and 4.2 and; 0.9 and 6.4 mg/l, respectively), spinosad (0.36 and 1.98, 0.45 and 1.35 and; 0.57 and 1.37 mg/l, respectively), chlorantraniliprole (0.04 and 0.2, 0.06 and 0.5 and; 0.08 and 0.9 mg/l, respectively) and emamectin benzoate (0.011 and 0.37, 0.017 and 0.51 and; 0.025 and 0.87 mg/l, respectively). On comparing with baseline data the resistance factors obtained were 0.2, 0.4 and 0.8 (flubendiamide), 0.6, 1.0 and 3.0 (indoxacarb), 0.007, 0.009 and 0.011 (spinosad), 1.3, 2.0 and 2.6 (chlorantraniliprole) and 1.1, 1.7 and 2.5 (emamectin benzoate) at 24, 48 and 72 hours after treatment, respectively. Larvae of *H. armigera* collected from Mahaboobnagar, Kurnool and Guntur district resistant to flubendiamide in the F1 and F2 generations showed positive cross-resistance to chlorantraniliprole of 1.25-fold in F1, 3.6-fold in F2 and 4.8-fold in the F3 generation, respectively. Chlorantraniliprole selected strain (F1 and F2) of Mahaboobnagar, Kurnool and Guntur district recorded positive cross-resistance to flubendiamide 6.3-fold in F1, 2.58-fold in F2 and 5.09-fold in the F3 generation, respectively.

Hussain *et al.* (2015) assessed the toxicity of selected insecticides against natural populations of *H. armigera* collected from three locations of Punjab, Pakistan during three consecutive years to identify possible levels of insecticide resistance and revealed that based on the calculated RRs, the field populations tested were highly resistant to bifenthrin (RR = 34.1 to 48.0), moderately to highly resistant to lambda-cyhalothrin (RR = 19.6 to 68.2) and deltamethrin (RR = 19.3 to 37.2); and minimally to moderately resistant to profenofos (RR = 9.80 to 12.11),

methoxyfenozide (RR = 6.0 to 11.8) and thiodicarb (RR = 5.6 to 11.5). Resistance was low for emamectin benzoate (RR = 1.7 to 5.2), chlorpyrifos (RR = 3.5 to 9.6) and lufenuron (RR = 1.0 to 2.2). Pairwise comparison of the log LC₅₀ of the insecticides against all populations showed a correlation among the various insecticides, suggested possible development of cross-resistance.

Liu *et al.* (2015a) investigated cyantraniliprole resistance in *Plutella xylostella* and revealed that the resistance of *P. xylostella* (designated Cya-SEL) to cyantraniliprole increased to 30.6 and 326-fold after 26 generations of selection, compared with the field population (TA) and susceptible population (LAB), respectively. The resistant population had also developed low to moderate levels of resistance to abamectin (3.3-fold), flubendiamide (14.1-fold) and chlorantraniliprole (24.3-fold). The degree of dominance and overlapping confidence intervals of LC₅₀ values of F1 progenies (ZC♀ × LAB♂ and LAB♀ × ZC♂) suggested an autosomal and incompletely recessive mode of resistance to cyantraniliprole. The test of monogenic inheritance based on a backcross of F1 progeny with the ZC population indicated that resistance to cyantraniliprole was controlled by multiple genes.

Liu *et al.* (2015b) revealed that after 52 generations of selection with chlorantraniliprole, 48.17-fold resistance was observed in *P. xylostella*. The resistant strain showed cross-resistance to flubendiamide (7.29-fold), abamectin (6.11-fold) and cyantraniliprole (3.31-fold). Quantitative real-time polymerase chain reaction analysis showed that the expression of the ryanodine receptor gene was higher in the resistant strain than that in the susceptible strain. Enzyme assays indicated that cytochrome P450 activity in the resistant strain was 4.26 times higher compared with the susceptible strain, whereas no difference

was seen for glutathione-S-transferase and esterase. Moreover, the toxicity of chlorantraniliprole in the resistant strain could be synergized by piperonyl butoxide, but not by diethyl maleate, and S, S, S-tributyl phosphorothioate.

Muhammad *et al.* (2015) studied baseline susceptibility and resistance stability to cypermethrin, deltamethrin and spinosad in a field collected population of *E. vittella* and exhibited that the baseline susceptibility values of *E. vittella* to cypermethrin, deltamethrin and spinosad were 1.24, 0.94 and 0.16, respectively. Resistance to tested insecticides was unstable and spinosad was more toxic than cypermethrin and deltamethrin. The results suggested that deltamethrin, cypermethrin and spinosad could be included in a control programme of *E. vittella* due to high reversion rates.

Qayyum *et al.* (2015) assessed insecticide resistance in field populations of *H. armigera* from 15 localities across the Punjab (Pakistan) by the leaf dip method against formulated insecticides and reported that resistance levels in *H. armigera* had been incrementally increasing for organophosphate and pyrethroid insecticides after decades of use. Resistance ratios (RRs) registered for organophosphates were 24 to 116-fold for profenofos and 22 to 87-fold for chlorpyrifos. For pyrethroids, RRs were 3 to 69-fold for cypermethrin and 3 to 27-fold for deltamethrin. Resistance levels against newer chemistries were 2 to 24-fold for chlorfenpyr, 1 to 22-fold for spinosad, 1 to 20-fold for indoxacarb, 1 to 18-fold for abamectin and 1 to 16-fold for emamectin benzoate. Resistant populations of *H. armigera* were mainly in the southern part of the Punjab, Pakistan. The most resistant populations were collected from Pakpattan, Multan and Muzzafargarh. Of the nine insecticides tested, LC₅₀ and LC₉₀ values were lower for newer

insecticide groups; resistance levels were moderate to very high against organophosphates, very low to high against pyrethroids and very low to low against the newer chemistry insecticides.

Adams *et al.* (2016) studied susceptibility of *Helicoverpa zea* neonates to diamide insecticides in the Midsouthern and Southeastern United States and exhibited that a higher concentration of flubendiamide was required compared to chlorantraniliprole to achieve equivalent levels of mortality. Flubendiamide LC₅₀ values for *H. zea* ranged from 16.45 to 30.74 ng per ml, with a mean of 23.53 ng per ml. Chlorantraniliprole LC₅₀ values for *H. zea* ranged from 2.94 to 4.22 ng per ml, with a mean of 3.66 ng per ml. Significant differences were observed for some field populations relative to the laboratory colony. For flubendiamide, five populations had greater LC₅₀ values and two populations had lower LC₅₀ values compared to the laboratory colony. For chlorantraniliprole, three populations had greater LC₅₀ values and three populations had lower LC₅₀ values compared to the laboratory colony. The response of these populations most likely represents natural variability among populations and did not indicate a significant shift in susceptibility of this species.

Agboyi *et al.* (2016) conducted bioassay on three populations of *P. xylostella*, two from Togo (Kara and Dapaong) and one from Benin (Cotonou) to assess their level of susceptibility to currently used insecticides and revealed that *P. xylostella* populations from Dapaong, Kara and Cotonou were more resistant to deltamethrin (13 to 59-fold at LC₅₀ level, 149 to 1772-fold at LC₉₀ level) and chlorpyrifos ethyl (5 to 15-fold at LC₅₀ level, 9 to 885-fold at LC₉₀ level) than the reference strain. Spinosad was more toxic to *P. xylostella* populations than the other insecticides with LC₅₀ and LC₉₀ values less than 1 and 15

µg per ml, respectively. However, the population from Cotonou appeared significantly more resistant to spinosad compared to the reference strain.

Bird (2016a) determined baseline susceptibility of *H. armigera* to cyantraniliprole by collecting field populations from eastern Australia and observed that intraspecific variation in cyantraniliprole susceptibility amongst field strains was 9.3-fold in topical bioassays (n = 23 strains) and 2.6-fold in ingestion bioassays (n = 31 strains). The median lethal concentration in field strains was 28 mg per liter in topical bioassays and 0.065 mg per liter in ingestion bioassays, demonstrated that cyantraniliprole was >400-fold more toxic when administered orally than by contact. The narrow range of intraspecific tolerance, high slope values, goodness-of-fit to the probit binomial model and enhanced toxicity in diet incorporation bioassays compared with topical bioassays suggested that delivery by ingestion was an effective laboratory method for measuring the dose-response of cyantraniliprole in *H. armigera*. A discriminating dose of 1.5 mg of cyantraniliprole per liter of diet was calculated from diet incorporation bioassays, as a first step in resistance management of cyantraniliprole in Australia.

Bird (2016b) investigated indoxacarb resistance in *H. armigera* and revealed that the level of indoxacarb resistance in the GY7-39 strain (indoxacarb resistant strain of *H. armigera*) was 139-198-fold compared with the susceptible strain. Genetic analysis showed that resistance was autosomal, incompletely dominant and conferred by one or a few closely linked loci. Indoxacarb resistance in the GY7-39 strain did not confer cross-resistance to chlorantraniliprole. The GY7-39 strain was more susceptible to emamectin benzoate, fenvalerate, Cry1Ac and Cry2Ab compared with the susceptible strain. Rapid selection of

indoxacarb resistance in the GY7-39 strain indicated the potential risk of resistance development to indoxacarb in field populations of *H. armigera*.

Carneiro *et al.* (2016) studied toxicity and sublethal effects of insecticides on *H. armigera* and found that spinosad was the product that had greater toxicity, requiring concentrations of only 0.01 and 0.05 l per ha to cause mortality of 50 and 95 per cent of subjects, respectively, compared with chlorantraniliprole and *B. thuringiensis*, causing LC₅₀ mortality at higher concentrations of 0.04 and 0.22 l per ha and LC₉₅ at 0.36 and 1.5 l per ha, respectively. In assessing the lethal effects, there was no difference between treatments for LC₂₅. The treatments of spinosad, chlorantraniliprole and *B. thuringiensis*, showed satisfactory results in concentrations of 0.006, 0.02 and 0.10 l per ha, causing mortality of 30, 22 and 20 per cent of the larvae, respectively. For LC₅₀, the best result was obtained for the spinosad treatment that resulted in 36.25 per cent mortality followed by chlorantraniliprole with 25 per cent.

Jat *et al.* (2016) carried out bioassay of new chemistry insecticides against *H. armigera* on chickpea and found that spinetoram was most effective in managing the 2nd instar larvae of *H. armigera* and it was followed by novaluron 10 EC and indoxacarb 15.8 EC as compared to cypermethrin 25 EC. Emamectin benzoate 5SG @ 1 x 10⁻⁷ to 1 x 10⁻⁹ per cent concentrations recorded 100 per cent mortality against 2nd instar larvae and LC₅₀ values for 3rd instar larvae was 0.00000000045%. Insecticides novaluron 10 EC, spinetoram 11.7 EC and cypermethrin 25EC did not show promising and consistent results against 3rd instar larvae of *H. armigera* at 24 hrs. LC₅₀ values of spinetoram, novaluron, indoxacarb, rynaxypyr, thiodicarb, quinalphos and cypermethrin were 0.000000277, 0.0000557, 0.00007409, 0.003749, 0.01072, 0.053602 and 0.04125 per cent, respectively, against second instar larvae of *H.*

armigera. It can be inferred from the study that spinetoram and emamectin benzoate could be the first choice for management of *H. armigera* in chickpea crop.

Ramya *et al.* (2016) studied field-evolved insecticide resistance in *P. xylostella* and found moderate to high level of resistance to chlorpyrifos, cypermethrin and acephate where the Oddanchatram population being the most resistant (275.61-fold, 108-fold and 52.07-fold for chlorpyrifos, cypermethrin and acephate, respectively). The resistance to chlorpyrifos varied among the populations with maximum of 276-fold variation with LC₅₀ ranging from 14 to 3866.9 ppm. The resistance to cypermethrin varied from 108-fold with LC₅₀ ranging from 22 to 2993 ppm. The resistance to acephate varied among the populations with 52-fold and the LC₅₀ ranging from 77-419 ppm. In case of spinosad, the resistance varied among the populations with 1.6-fold and the LC₅₀ ranging from 3.3-9.7 ppm. The resistance to indoxacarb varied among the populations with 27.8-fold with LC₅₀ ranging from 18-500.3 ppm. The resistance to novoluron varied among the populations with 1.6-fold and the LC₅₀ ranging from 1.8-5.6 ppm. This study indicated that spinosad, indoxacarb and novoluron were best for the control of *P. xylostella* in India.

Reddy and Bhamare (2016) monitored insecticide resistance in field populations of *E. vittella* collected from different locations of Marathwada region of Maharashtra and revealed that *E. vittella* populations of Marathwada had developed moderate level of resistance to quinalphos and lambda-cyhalothrin (up to 13-fold). While other field populations showed minor changes in their susceptibility to these insecticides. Low variations of susceptibility to emamectin benzoate, chlorantraniliprole and cyantraniliprole (<3-fold) was observed among

field populations and no obvious resistance to these products were observed. *E. vittella* population of Beed recorded 12.81-fold resistance to quinalphos 25% EC which was higher than other field populations. The resistance ratios varied greatly among the populations viz., quinalphos 25% EC (12.81- to 8.63-fold), lambda-cyhalothrin 5% EC (11.63- to 7.38-fold), emamectin benzoate 5% SG (2.37- to 1.56-fold), chlorantraniliprole 18.5% SC (2.1- to 1.30-fold) and cyantraniliprole 10.26% OD (1.94- to 1.40-fold).

Sang *et al.* (2016) studied the susceptibilities of *S. litura* collected from South China to cyantraniliprole by standard leaf-disc bioassay and observed obvious variation in susceptibility among the 17 field populations with varying LC₅₀ values from 0.206 to 1.336 mg a.i. per *l*. Significant correlations were detected between the LC₅₀ values of cyantraniliprole and chlorantraniliprole. However, no significant correlation was observed between the two anthranilic diamides and other insecticides with different action mechanisms (deltamethrin, chlorpyrifos, indoxacarb and emamectin benzoate). The results revealed obvious regional variation in cyantraniliprole susceptibilities among populations of *S. litura* from different areas and potential cross-resistance to chlorantraniliprole, which suggested that *S. litura* could develop resistance to cyantraniliprole. Detoxification enzymes might not be involved in the observed tolerance in field-collected populations and the cyantraniliprole-resistant strain.

Silva *et al.* (2016) monitored development of resistance in field collected populations of *Tuta absoluta* (Meyrick) from Northeast and Central regions of Brazil and proved that diagnostic and label doses of diamides recorded reduced efficacy against most populations. The LC₅₀ values of chlorantraniliprole varied from 0.0044 (Brasilia) to 1,263

(America Dourada) mg a.i. per *l* (the resistance ratios [RR₅₀] ranged from 1.0- to 288,995-fold, whereas the LC₅₀ values for cyantraniliprole and flubendiamide, respectively, varied from 0.015 (Brasilia) to 281 (America Dourada) mg a.i. per *l* and from 0.038 (Guaraciaba do Norte) to 3,018 (Gameleira 1) mg a.i. per *l*. The resistance ratios (RR₅₀) ranged from 1.0- to 18,423-fold for cyantraniliprole and from 1.0- to 80,413-fold for flubendiamide. The log LC₅₀ values of pairwise diamides were strongly and significantly correlated, which denoted cross-resistance among them. Very high level of resistance was observed to diamides in *T. absoluta*.

Bird *et al.* (2017) performed F2 screens for detection of resistance alleles in *H. armigera* to emamectin benzoate, chlorantraniliprole and indoxacarb in major cropping regions of eastern Australia and reported that resistance to emamectin benzoate was not detected. There were low but detectable levels of survival at discriminating concentrations of chlorantraniliprole and indoxacarb. Alleles conferring an advantage to chlorantraniliprole were present at a frequency of 0.0027 (95% CI 0.0012-0.0064; n_□=□1,817). Alleles conferring an advantage to indoxacarb were present at a frequency of 0.027 (95% CI 0.020-0.035; n_□=□1,863). Complementation tests for allelism in six of seven positive indoxacarb tests indicated that resistance was due to alleles present at the same locus. The majority (88%) of lines that tested positive for indoxacarb resistance deviated from a model of recessive inheritance.

Karjule *et al.* (2017) monitored development of insecticidal resistance in *H. armigera* infesting pigeonpea collected from different locations of Marathwada region of Maharashtra, India (Aurangabad, Jalna, Parbhani, Nanded, Beed, and Osmanabad). Based on variations in LC₅₀ values and comparison with recommended dosages, the insecticidal

resistance in *H. armigera* from different locations of Marathwada region was quite alarming to commonly used insecticides viz., chlorantraniliprole, cyantraniliprole, emamectin benzoate, indoxacarb and spinosad. *H. armigera* population infesting pigeonpea from Parbhani recorded 12.81-fold resistance to spinosad 45% SC which was higher than other field populations. The resistance ratios varied greatly among the populations viz., spinosad 45% SC (12.81- to 8.64-fold), indoxacarb 15.8% EC (10.89- to 6.94-fold), emamectin benzoate 5% SG (2.54- to 2.09-fold), cyantraniliprole 10.26% OD (2.10- to 1.74-fold) and chlorantraniliprole 18.5% SC (1.96- to 1.13-fold). High resistance factor of spinosad 45% SC and indoxacarb 15.8% EC against all field populations of pigeonpea pod borer revealed development of resistance against these insecticides.

Karuppaiah *et al.* (2017) studied carboxylesterase-mediated insecticide resistance in *S. litura* with three different populations from Varanasi, Delhi and Sonapat and evidenced that the LC₅₀ values of cypermethrin were 210, 220 and 100 ppm and bifenthrin were 148, 151 and 85 ppm for Delhi, Sonapat and Varanasi population, respectively. The trend of cypermethrin and bifenthrin toxicity was Sonapat > Delhi > Varanasi population. The Delhi and Sonapat field population registered 2.1- and 2.2-fold higher LC₅₀ for cypermethrin and 1.77- and 1.78-fold higher LC₅₀ for bifenthrin than that of the Varanasi susceptible population.

Liu *et al.* (2017) tested the toxicity of 23 commonly used insecticides on *H. armigera*, *Agrotis ipsilon* and *S. litura* moths under laboratory conditions and revealed that chlorantraniliprole, emamectin benzoate, spinetoram, spinosad and methomyl exhibited high levels of toxicity to *H. armigera* moths with a mortality of 86.67, 91.11, 73.33,

57.78 and 80.00 per cent, respectively, during 24 h period at the concentration of 1 mg a.i. per *l*. Among these five insecticides, *A. ipsilon* and *S. litura* moths were more sensitive to chlorantraniliprole, emamectin benzoate and methomyl. The lethal time (LT₅₀) values of chlorantraniliprole and methomyl were shorter than emamectin benzoate for all three lepidopteran moth species at 1000 mg a.i. per *l* compared to concentrations of 500, 100 and 1 mg a.i per *l*. Chlorantraniliprole showed similar levels of toxicity and lethal time on the three lepidopteran moths tested to the standard methomyl and therefore, could be used as an alternative insecticide to methomyl in the attracticide for controlling these pest species.

Pan *et al.* (2017) studied levels of resistance in field population of *H. armigera* from Qiuxian to 6 insecticides and revealed that Qiuxian population kept high levels of resistance to cyhalothrin (RR = 61.8-95.2) and beta-cypermethrin (RR = 50.9-82.3), low to moderate levels of resistance to phoxim (RR = 9.1-23.7) and; susceptibility to emamectin benzoate, abamectin and spinosad. Emamectin benzoate, abamectin and spinosad were found to be the alternative options for controlling *H. armigera* in Qiuxian County, if the efficacy of *Bt* cotton would be compromised by *Bt* resistance in the field.

Roditakis *et al.* (2017) investigated the molecular basis of diamide resistance in a diamide resistant strain of *T. absoluta* from Italy (IT-GELA-SD4) and additional resistant field populations collected in Greece, Spain and Brazil. The genetics of resistance was investigated by reciprocally crossing strain IT-GELA-SD4 with a susceptible strain and revealed an autosomal incompletely recessive mode of inheritance. Genotyping of individuals of IT-GELA-SD4 and field-collected strains showing different levels of diamide resistance revealed the presence of

G4903E and I4746M RyR target-site mutations. These amino acid substitutions correspond to those recently described for diamide resistant diamondback moth, i.e. G4946E and I4790M. Two novel mutations, G4903V and I4746T were detected in some of the resistant *T. absoluta* strains. Radioligand binding studies with thoracic membrane preparations of the IT-GELA-SD4 strain provided functional evidence that these mutations altered the affinity of the RyR to diamides.

Sattar *et al.* (2017) demonstrated dose-response relationship of some insecticides with *H. armigera* and revealed that emamectin benzoate recorded minimum LC₅₀ value (1.650 mg per *l*) followed by neem oil (24.561 mg per *l*), flubendiamide (36.506 mg per *l*), lufenuron (41.232 mg per *l*), spinosad (57.403 mg per *l*), indoxacarb (91.872 mg per *l*), thiodicarb (8843.111 mg per *l*) and deltapos (9035.215 mg per *l*). Results showed that emamectin benzoate was most potent, followed by flubendiamide, lufenuron, spinosad, indoxacarb and neem oil. Spinosad, closely followed by indoxacarb and flubendiamide were the quickest in exerting their lethal effect on the larvae. The pest expressed mild level of tolerance against deltapos and thiodicarb with LC₅₀ and LT₅₀ values much higher than their respective FRCs and the rest of insecticides.

Sreelakshmi *et al.* (2017) investigated insecticide resistance in field populations of *S. litura* collected from three districts of Kerala against chlorpyrifos, quinalphos, lambda-cyhalothrin and cypermethrin and showed that population collected from Aleppy was found to be susceptible for all the chemicals tested with resistance ratio 1-fold, population collected from Thiruvananthapuram was found to be resistant for chlorpyrifos, quinalphos, lambda cyhalothrin and cypermethrin with resistance ratios of 6.14, 2.46, 8.50 and 6.47-fold, respectively followed by Pathanamthitta with resistance ratios of 2.62, 1.03, 2.29 and 1.34-fold,

respectively. The LC₅₀ values of chlorpyrifos in the population of *S. litura* collected from Aleppy, Pathanamthitta and Thiruvananthapuram were 0.64, 1.68 and 3.93 ppm after 48 hours of treatment, respectively. The LC₅₀ values of lambda-cyhalothrin in the population of *S. litura* collected from Aleppy, Pathanamthitta and Thiruvananthapuram were 3.05, 7.00 and 25.93 ppm after 48 hours of treatment, respectively. The LC₅₀ values of cypermethrin in the population of *S. litura* collected from Aleppy, Pathanamthitta and Thiruvananthapuram were 1.98, 2.67 and 12.83 ppm after 48 hours of treatment, respectively.

Su *et al.* (2017) assayed toxicity and persistence of chlorantraniliprole against larvae of cabbage, *Pieris rapae* on cabbage and expressed that the LC₅₀ value of chlorantraniliprole for early and later *P. rapae* larvae were 7.92 and 11.34 mg per l by contact toxicity, respectively. The LC₅₀ value of chlorantraniliprole for early and later *P. rapae* larvae were 0.95 and 4.32 mg per l through ingestion, respectively. The toxicity of field-aged leaf residues of chlorantraniliprole (0-, 3-, 5-, 7-, 10-, 14-, 21-, 25- and 28-day-old residues) declined gradually under the field conditions. Almost all larvae died on day 5 after feeding on the leaves with 0-21-day residue and the mortalities were as high as 83.3 and 72.5 per cent for the 21- and 25-day-old leaf residues. In addition, chlorantraniliprole was as effective as indoxacarb and spinosad and significantly more effective than emamectin benzoate.

Trocza *et al.* (2017) found rapid selection for resistance to diamide insecticides in *P. xylostella* via specific amino acid polymorphisms in the ryanodine receptor. Diamide insecticides, such as flubendiamide and chlorantraniliprole, were a new class of insecticide with a novel mode of action, selectively activating the insect ryanodine receptor (RyR). Resistant phenotypes collected from different countries

could often be linked to specific target site mutation(s) in the ryanodine receptors' transmembrane domain. Metabolic mechanisms of resistance had also been proposed. Rapid resistance development was probably a consequence of overreliance on this one class of chemistry for *P. xylostella* control.

Meghana *et al.* (2018) exhibited the variations in relative susceptibility levels among the populations of *P. xylostella* collected from South Karnataka and revealed that the LC₅₀ values were varied across insecticides for single population and also across the populations of geographical locations. The LC₅₀ value of Bengaluru, Kolar and Chikkaballapura populations recorded highest for dichlorvos 76 EC (15.63, 31.82 and 22.51 µg a.i. ml per *l*) and the lowest LC₅₀ value of Bengaluru, Kolar and Chikkaballapura populations recorded for emamectin benzoate 5 SG (3.13, 5.86 and 3.42 µg a.i. ml per *l*), cyantraniliprole 10.26 OD (4.43, 4.48 and 4.48 µg a.i. ml per *l*) and spinosad 45 SC (4.22, 5.88 and 2.48 µg a.i. ml per *l*) was found to be highly toxic to the third instar larvae of *P. xylostella*. This clearly indicated that the rate of evolution of resistance in *P. xylostella* was varied across insecticides and also across geographical locations.

Yeole *et al.* (2018) studied resistance of chlorantraniliprole in *P. xylostella* collected from different locations of Maharashtra and revealed that the LC₅₀ values for larvae of *P. xylostella* exposed to chlorantraniliprole 18.5 SG ranged from 0.0390 to 0.0063 ml per *l*. The Nashik population recorded a maximum LC₅₀ value to chlorantraniliprole 18.5 per cent SG (0.039 ml per *l*) followed by Ahmednagar (0.019 ml per *l*), Osmanabad (0.0145 ml per *l*), Solapur (0.011 ml per *l*), Pune (0.0085 ml per *l*) and Latur (0.0063 ml per *l*). However, LC₅₀ value of susceptible strain of *P. xylostella* to chlorantraniliprole 18.5 SG was 0.039 ml per *l*.

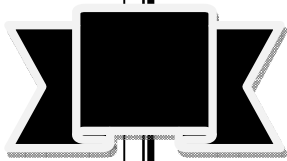
The resistance ratio to chlorantraniliprole 18.5 SG was found to be highest in *P. xylostella* population of Nashik (12.8-fold) followed by Ahmednagar (6.25-fold), Osmanabad (4.76-fold), Solapur (3.62-fold), Pune (2.80 -fold) and Latur (2.07-fold). Compared with the susceptible strain only Nashik population of *P. xylostella* (12.8-fold) indicated low resistance while, other field populations (83.33 per cent) *i.e.* Osmanabad, Solapur, Pune, Latur and Ahmednagar showed decreased susceptibility to chlorantraniliprole 18.5 SG. Compared with the susceptible strain only Nashik population (16.66 per cent) indicated moderate level of resistance while, other 2 of 6 field populations (33.33 per cent) *i.e.*, Solapur and Osmanabad showed decreased susceptible to chlorantraniliprole 18.5 SG.

Shanmugapriya *et al.* (2019) studied baseline toxicity of diamide group of insecticides against *P. xylostella* collected from different locations of Tamil Nadu and indicated that the LC₅₀ values were varied across insecticides for single population and also across the populations of geographical locations. The LC₅₀ values of the different population in Coimbatore, Ooty, Oddanchatram, Krishnagiri and Theni for flubendiamide, chlorantraniliprole and Cyantraniliprole were 0.113, 0.181, 0.172, 0.129 and 0.108; 0.104, 0.137, 0.128, 0.171 and 0.118 and; 0.010, 0.012, 0.014, 0.011 and 0.011 mg per ml, respectively. The LC₅₀ values of the susceptible population for flubendiamide 20 WG, chlorantraniliprole 18.5 SC and cyantraniliprole 10.26 OD were 0.021, 0.048 and 0.007 mg per ml, respectively. Cyantraniliprole 10.26 OD proved to be the best in toxicity to all the geographic population compared to chlorantraniliprole 18.5 SC and flubendiamide 20 WG. The resistant ratio was also significantly low compared to chlorantraniliprole and flubendiamide (1.43, 1.71, 2.00, 2.43, and 1.57 in Coimbatore, Ooty, Oddanchatram, Krishnagri and Theni, respectively). The resistant ratio

was higher in flubendiamide 20 WG (5.143 to 8.619) and chlorantraniliprole 18.5 SC (2.167 to 3.562) than cyantraniliprole 10.26 OD (1.43 to 2.43) in all five different locations.

Sharma *et al.* (2019) studied relative toxicity of newer insecticides against *S. litura* and *P. brassicae* infesting Cole crops in Punjab and revealed that chlorantraniliprole, spinosad, flubendiamide, novaluron and emamectin benzoate were 52.0, 52.0, 17.33, 2.74 and 2.60 times toxic to third instar larvae of *S. litura*, while *P. brassicae* was observed to be relatively more sensitive to these insecticides with relative toxicity to emamectin benzoate, indoxacarb, flubendiamide, novaluron, chlorantraniliprole being 85.71, 42.86, 6.0, 3.0 and 3.0, respectively. The LT_{50} values of these insecticides varied from 62.36 (indoxacarb) to 78.12 h (flubendiamide) against *S. litura* and 67.11 (spinosad) to 82.57 h (flubendiamide) against *P. brassicae*. The LC_{50} values of chlorantraniliprole, spinosad, flubendiamide, emamectin benzoate, indoxacarb and novaluron were computed to be 0.001, 0.001, 0.03, 0.020, 0.052 and 0.019 ppm, respectively against third instar larva of *S. litura* while for of *P. brassicae*, LC_{50} values were computed to be 0.002, 0.006, 0.01, 0.00007, 0.00014 and 0.002 ppm, respectively.

MATERIAL AND
METHODS



Chapter III

MATERIAL AND METHODS

The present investigation was undertaken with an objective to monitor the levels of insecticide resistance in the field populations of *Leucinodes orbonalis* Guenee infesting brinjal collected from different locations of Western Maharashtra against commonly used insecticides. The laboratory studies were conducted at Post Graduate Laboratory, Department of Agricultural Entomology, College of Agriculture, Latur (Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra) during 2018-19. The material required and the methods adopted during the course of present investigations are described under the following heads.

3.1 Collection, transport and rearing of L1 larvae

3.2 Rearing of susceptible population

3.3 Details of insecticides used in bioassay

3.4 Preparation of insecticide solutions

3.5 Bio-assay for *Leucinodes orbonalis* resistance to insecticide

3.1 Collection, transport and rearing of L1 larvae

Leucinodes orbonalis infested fruits were collected from brinjal fields grown in different districts of Western Maharashtra and transported immediately to Post Graduate Laboratory, Department of Agril. Entomology, College of Agriculture, Latur for further culturing. The field collected L1 larvae were reared in round plastic vials (measuring 4 cm diameter and 5 cm height) and transparent plastic boxes (measuring 26 cm L × 17 cm W x 6 cm H) by feeding them on natural diet (shoots and fruits) every day till pupation. The pupae were transferred to round clean plastic containers (measuring 16 cm diameter

and 16 cm height) covering top with muslin cloth secured firmly with rubber band. The sexes were determined in pupal stages on the basis of distance between genital and anal apertures. It is less in the case of male and more in the case of female (Srivastava and Pande, 1966 and Dani *et al.*, 1980). The freshly emerged adults were released into standard oviposition cage (measuring 50 cm x 30 cm) covered with black muslin cloth. The proportion of female and male in the cage was 1:1 in order to get fertilized eggs. Cotton swab dipped into 10 per cent honey solution was provided to serve as food for the adults. A strip of cotton cloth toweling (6×17 cm) was hung vertically inside each oviposition cage as oviposition substrate. The eggs on the toweling were kept in a transparent plastic box (measuring 26 cm L × 17 cm W x 6 cm H). The eggs from each pair were kept separately. After hatching, neonate larvae were transferred separately into plastic vials (diameter 15 cm). The larvae were fed daily on natural diet. The 2nd instar larvae of 'F-1' generation were used for conducting the bioassay studies.

The rearing of *L. orbonalis* populations collected from different districts of Western Maharashtra were carried out separately at ambient room temperature of 28 ± 3 °C.

3.2 Rearing of susceptible population

The susceptible population of *L. orbonalis* was developed by rearing five generations of *L. orbonalis* without selection pressure of any insecticide under laboratory conditions.

3.3 Details of insecticides used in bioassay

The insecticides which are widely used by farmers were selected for studying the levels of insecticidal resistance in *L. orbonalis*

infesting brinjal fruits. The details of the insecticides used are presented in Table 1.

Table 1: Insecticides used for *Leucinodes orbonalis* bioassay

Sr. No.	Insecticides	Trade name	Name of company	Recommended dose per 10 litres of water
1.	Chlorantraniliprole 18.5% SC	Coragen	Dupont Pvt. Ltd.	3 ml
2.	Chlorpyrifos 20% EC	Force	Nagarjuna Agrichem Ltd	6.6 ml
3.	Cyantraniliprole 10.26% OD	Benevia	Dupont Pvt. Ltd.	18 ml
4.	Cypermethrin 25% EC	Cymbush	Syngenta Group of Companies Ltd.	3 ml
5.	Emamectin benzoate 5% SG	Starclaim	Swal Corporation Ltd.	4.4 g
6.	Dimethoate 30% EC	Tafgor	Rallis India Ltd.	13.2 ml
7.	Fenprothrin 30% EC	Meothrin	Sumitomo Chemical Co. Ltd	30 ml
8.	Lambda-cyhalothrin 5% SC	Agent plus	Indofil Industries Ltd.	1.5 ml
9.	Thiacloprid 21.7% SC	Alanto	Bayer Crop Science Ltd.	15 ml

3.4 Preparation of insecticidal solution

All the insecticides were procured as market samples and dilutions required were prepared from the formulated product only with distilled water. In *L. orbonalis* bioassay each insecticide was used in five concentrations (two lower than recommended, one recommended and two higher than recommended) rendering 20 to 80 per cent mortality in pilot

tests. However, care was taken to retain the recommended dosage of each insecticide as one of the concentrations.

3.5 Bio-assay for *L. orbonalis* resistance to insecticide

3.5.1 Bioassays studies

Newly moulted 2nd instar larvae of *L. orbonalis* from F₁ laboratory culture was exposed to different insecticides using shoot and fruit dip method (IRAC Method No. 7) recommended by Insecticide Resistance Action Committee with slight modification.

Formulated insecticides were diluted using distilled water as a solvent. Sufficient numbers of non-infested, untreated and fresh fruits were collected from unsprayed plots and brought to the laboratory. Then brinjal fruits were sliced and dipped into the respective test solutions for 60 seconds. Upon drying on paper towel, these slices were transferred to labelled and clean petri plates as per the treatments. Ten newly moulted 2nd instar F₁ larvae of *L. orbonalis* were placed on dried fruit slices and the petri plate was covered. Ten larvae per treatment per replication were exposed to the treated fruit slices. Three replicates each of five concentrations and one control (distilled water) were used for each test insecticide at ambient room temperature. Observation on larval mortality was recorded after a 48 hrs of exposure period. Larvae were regarded as dead when it was not able to move when probed with a blunt probe or brush.

The setup of bioassays was maintained separately for every location. The mortality data of each treatment were corrected with respect to control mortality as per Abbott formula (1925) for *L. orbonalis* bioassays.

Abbott's formula:

$$\text{Corrected per cent mortality} = \frac{T-C}{100-C} \times 100$$

Where,

T - Per cent mortality in treatment

C - Per cent mortality in control

3.5.2 Median lethal concentration (LC₅₀)

The value of median lethal concentration (LC₅₀) for each insecticide was worked out using Probit analysis by Finney (1971) and by computer software Polo Plus 1.0 (LeOra software, 2003). Similarly, LC₅₀ values of these insecticides against the susceptible population of *L. orbonalis* infesting brinjal were calculated. LC₅₀ values of field collected population was compared with the LC₅₀ values of susceptible strain to know the level of resistance.

3.5.3 Resistance ratio

The resistance intensity of insect population to particular insecticide is quoted as Resistance Ratio (RR). Sometimes it is also called Resistance Factor (RF) (Pate and Bhamare, 2016) which was calculated by following formula:

$$\text{Resistance Ratio (RR)} = \frac{\text{LC}_{50} \text{ of Resistance Strain (RS)}}{\text{LC}_{50} \text{ of Susceptible Strain (SS)}}$$

4.0 Scale of Resistance ratio or factor

RR values were used to indicate resistance levels or categories according to Wang *et al.* (2017) and Reddy and Bhamare (2016): RR values < 3 indicated sensitive or susceptible populations; values from 3.1-5.0 and from 5.1-10.0 indicated decreased sensitivity or susceptibility and low resistance, respectively; values from 10.1-40.0 and from 40.1-160 indicated medium or moderate resistance and high resistance, respectively; and values >160 indicated extremely high resistance.

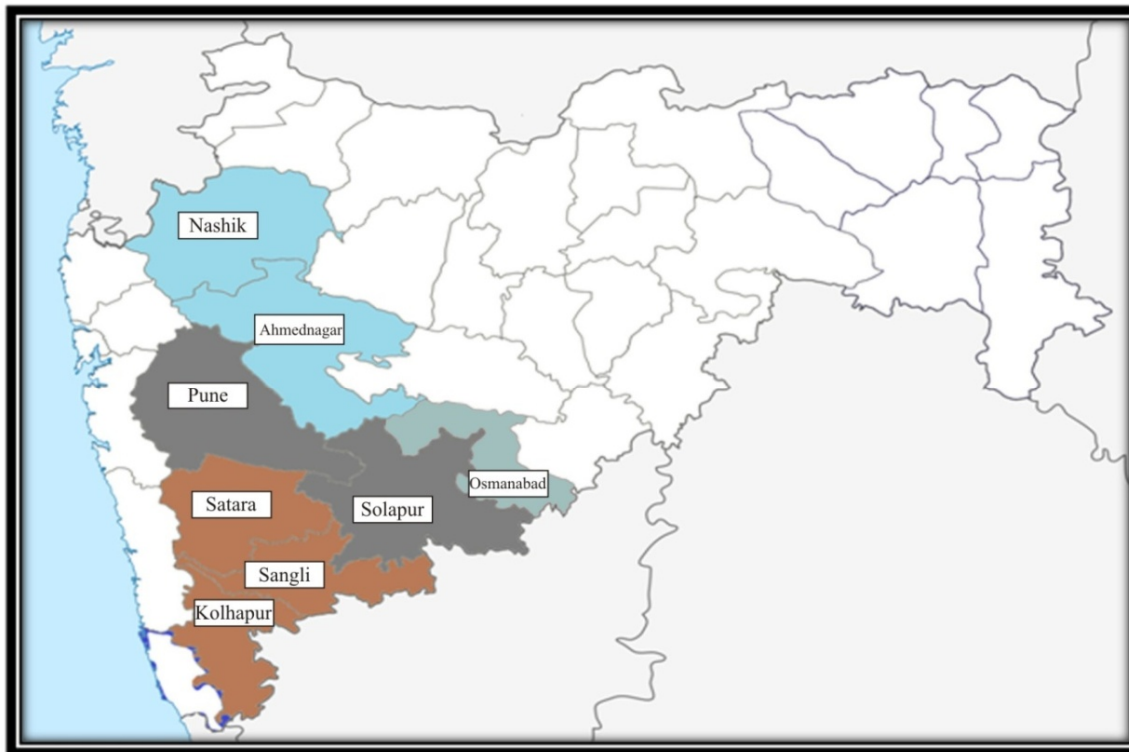


Fig.1. Sampling sites of *Leucinodes orbonalis* (Guenee) infesting Brinjal (Western Maharashtra, India)



Plate I: Preparation of insecticidal solution

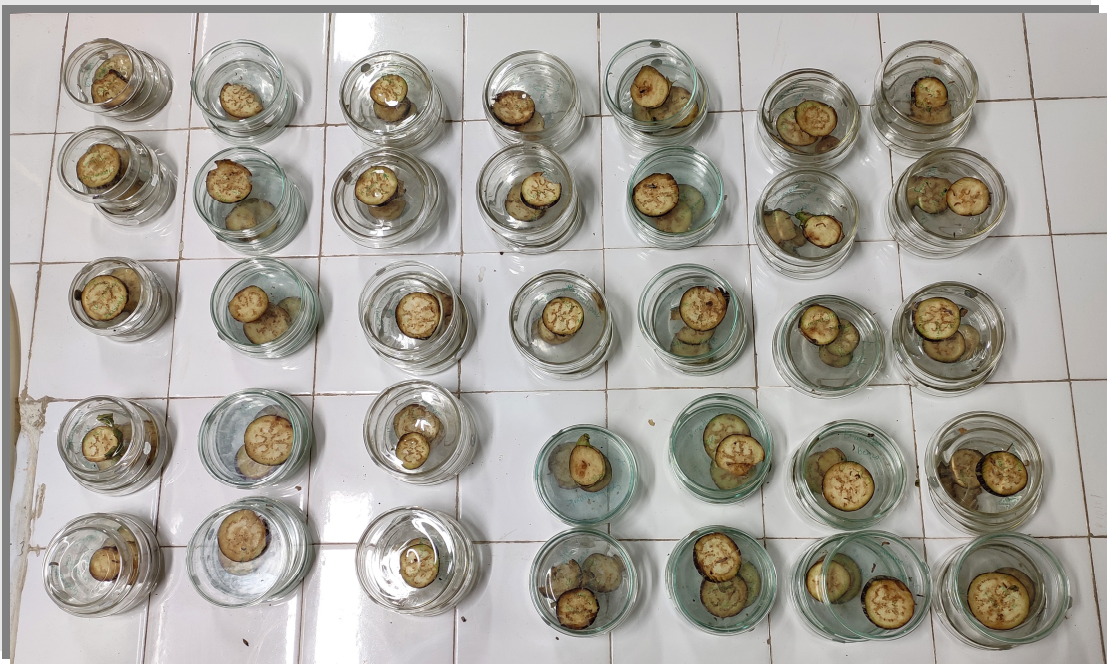
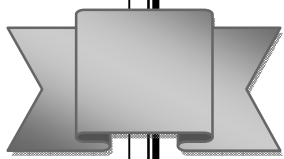


Plate II: Bioassay set up of *Leucinodes orbonalis* (IRAC Method No. 7)



RESULTS & DISCUSSION

Chapter IV

RESULTS AND DISCUSSION

The present investigation was carried out to monitor the levels of insecticidal resistance in field populations of *Leucinodes orbonalis* (Guenee) infesting brinjal collected from different districts of Western Maharashtra against commonly used insecticides. The laboratory investigations were conducted at the Post Graduate Laboratory, Department of Agricultural Entomology, College of Agriculture, Latur (Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra) during 2018-19. The results obtained during the course of investigations are presented under the following heads.

4.1 Chlorantraniliprole 18.5% SC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on the degrees of resistance acquired by *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to chlorantraniliprole 18.5% SC are presented in Table 2 and depicted in Fig. 2. The results of comparison of LC₅₀ values in different populations of *L. orbonalis* revealed that different populations had diverse levels of resistance. LC₅₀ values for larvae of *L. orbonalis* exposed to chlorantraniliprole 18.5% SC ranged from 0.00101 to 0.00177 ml per *l*. The Pune population recorded a maximum LC₅₀ value to chlorantraniliprole 18.5% SC (0.00177 ml per *l*) followed by populations from Nashik (0.00170 ml per *l*), Kolhapur (0.00169 ml per *l*), Solapur (0.00156 ml per *l*), Sangli (0.00153 ml per *l*), Ahmednagar (0.00142 ml per *l*), Satara (0.00119 ml per *l*) and Osmanabad (0.00101 ml per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to chlorantraniliprole 18.5% SC was 0.00053 ml per *l*.

Table 2: Chlorantraniliprole 18.5% SC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.00142	0.00028	0.00262	0.05571	0.804 ± 0.262	0.6981	2.68
2	Kolhapur	0.00169	0.00037	0.00307	0.07863	0.769 ± 0.256	0.0317	3.19
3	Nashik	0.00170	0.00043	0.00300	0.06291	0.818 ± 0.260	1.0293	3.21
4	Pune	0.00177	0.00071	0.00280	0.03033	1.038 ± 0.272	2.1004	3.34
5	Sangli	0.00153	0.00026	0.00289	0.08220	0.741 ± 0.256	0.1361	2.89
6	Satara	0.00119	0.00011	0.00246	0.07925	0.703 ± 0.259	1.4475	2.25
7	Solapur	0.00156	0.00038	0.00277	0.05432	0.831 ± 0.262	0.7223	2.94
8	Osmanabad	0.00101	0.00008	0.00217	0.06256	0.716 ± 0.261	0.0228	1.91
9	Susceptible	0.00053	0.00004	0.00123	0.01347	0.910 ± 0.300	0.2429	-

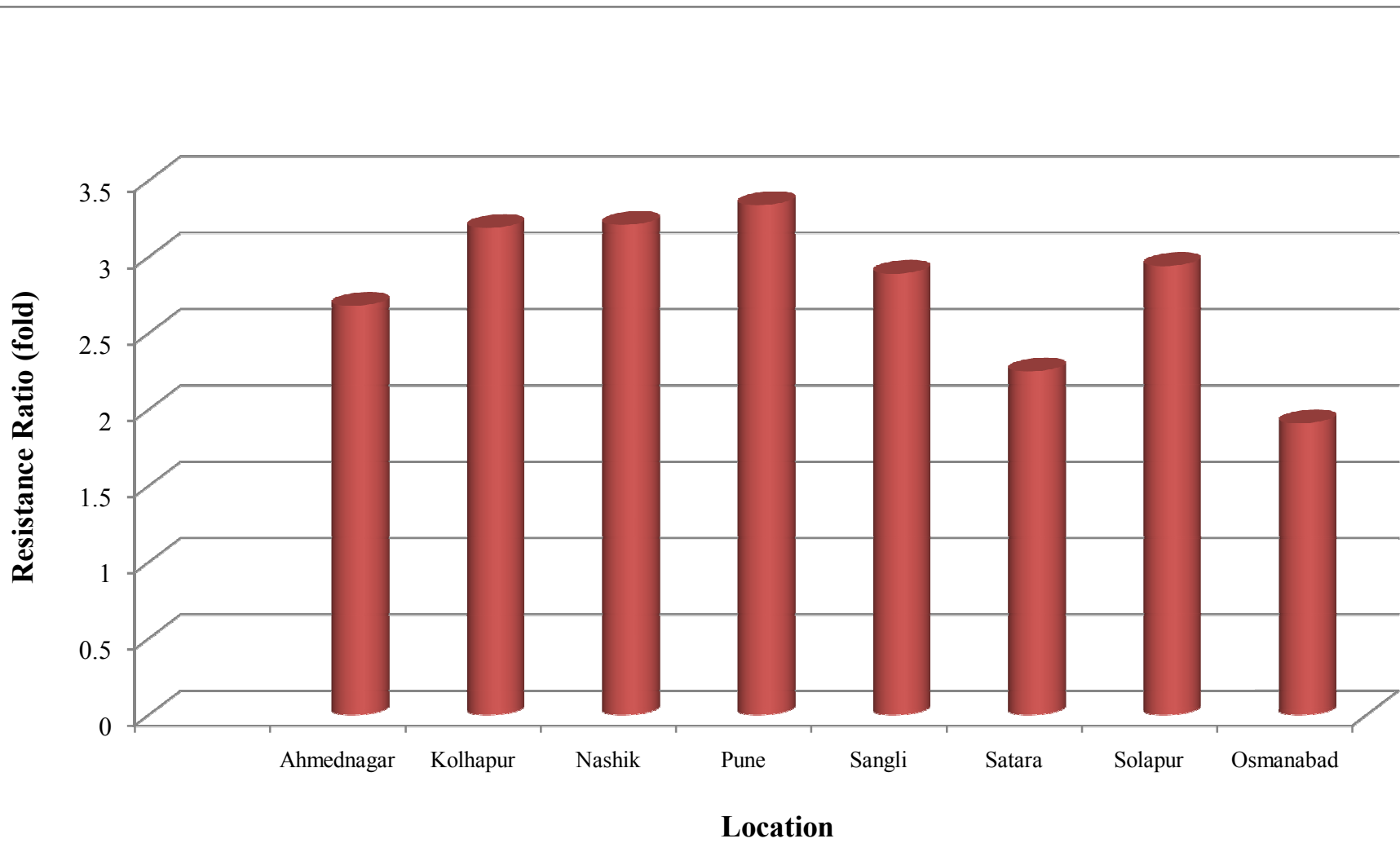


Fig. 2. Chlorantraniliprole 18.5% SC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

The resistance ratio of chlorantraniliprole 18.5% SC was found to be highest in *L. orbonalis* population of Pune (3.34-fold) followed by Nashik (3.21-fold), Kolhapur (3.19-fold), Solapur (2.94 - fold), Sangli (2.89-fold), Ahmednagar (2.68-fold), Satara (2.25-fold) and Osmanabad (1.91-fold). There was 1.75-fold difference in LC₅₀ values of Pune and Osmanabad strains among the field populations. The result showed that 3 of 8 field populations (37.5 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Pune, Nashik and Kolhapur showed decreased susceptibility to chlorantraniliprole 18.5% SC. However remaining 5 of 8 field populations (62.5 per cent) of *L. orbonalis* collected from Solapur, Sangli, Ahmednagar, Satara and Osmanabad exhibited susceptibility to chlorantraniliprole 18.5% SC.

These results are in compliance with the findings of Kate (2018) who studied development of insecticide resistance in *L. orbonalis* infesting brinjal and exhibited that *L. orbonalis* population collected from different locations of Marathwada indicated susceptibility to chlorantraniliprole 18.5% SC with varied level of resistance (2.0- to 2.4-fold). Sharma *et al.* (2018) evidenced that chlorantraniliprole 0.007 per cent showed highest Persistent Toxicity (PT) (449.16 and 437.50, respectively) and LT₅₀ values (5.16 and 4.99 days, respectively) during 2015 and 2016 against *L. orbonalis* compared to other insecticides at Palampur. Kodandaram *et al.* (2017) evidenced that *L. orbonalis* observed large variation in the susceptibility to chlorantraniliprole (LC₅₀ value of 0.157 mg a.i. per *l*). The significant increase in the LC₅₀ values of chlorantraniliprole (0.097 to 0.157 mg a.i. per *l*) was noticed in the population of *L. orbonalis* over the period of two years, indicated faster development of resistance to diamide insecticides (1.62-fold).

Kodandaram *et al.* (2015) exhibited that *L. orbonalis* were susceptible to chlorantraniliprole and recorded 82.00 and 100 per cent larval mortality at 24 and 48 hrs after treatment, respectively. The LC₅₀ value of *L. orbonalis* to chlorantraniliprole was found to be 1.8 ppm. Botre *et al.* (2014) reported that LC₅₀ values of rynaxypyr (chlorantraniliprole) to field strain of *L. orbonalis* were in the range of 0.127 to 0.157 ppm. Kaur *et al.* (2014) illustrated that the LC₅₀ values of chlorantraniliprole against Amritsar, Malerkotla and Hoshiarpur populations of *L. orbonalis* were 0.74, 0.092 and 0.38 ppm, respectively. Munje *et al.* (2015) revealed that LC₅₀ values of rynaxypyr to *L. orbonalis* ranged from 0.127-0.157 in Vidarbha. Ranjith Kumar (2014) found that among the populations, Raichur population of *L. orbonalis* recorded the maximum LC₅₀ values (2.15 and 2.30 ppm) and higher degree of resistance (1.30 and 1.35-fold) to rynaxypyr during 2009-10 and 2010-11. Kodandaram *et al.* (2013) revealed that chlorantraniliprole was highly effective against *L. orbonalis* and recorded the LC₅₀ value of 0.00018 per cent (1.8 ppm). The results of relative toxicity revealed that chlorantraniliprole was 6.2 times more toxic to *L. orbonalis* as compared to flubendiamide.

More or less similar trend in results were obtained by Shanmugapriya *et al.* (2019) who indicated that the LC₅₀ values for chlorantraniliprole 18.5 SC to *P. xylostella* populations collected from Coimbatore, Ooty, Oddanchatram, Krishnagiri and Theni were 0.104, 0.137, 0.128, 0.171 and 0.118 mg per ml, respectively. The LC₅₀ value of the susceptible population for chlorantraniliprole 18.5 SC was 0.048 mg per ml. Sharma *et al.* (2019) revealed that the LC₅₀ value of chlorantraniliprole was 0.001 ppm against third instar larvae of *S. litura* while for *P. brassicae*, LC₅₀ value was 0.002 ppm. Yeole *et al.* (2018) revealed that resistance ratio of chlorantraniliprole 18.5 SG was found to

be highest in *P. xylostella* population of Nashik (12.8-fold) followed by Ahmednagar (6.25-fold), Osmanabad (4.76-fold), Solapur (3.62-fold), Pune (2.80 -fold) and Latur (2.07-fold). Karjule *et al.* (2017) exhibited that all the populations of *H. armigera* indicated susceptibility to chlorantraniliprole 18.5% SC with varied level of resistance in the range of 1.13- to 1.96-fold. Bird *et al.* (2017) noticed low but detectable levels of survival of *H. armigera* at discriminating concentrations of chlorantraniliprole. Liu *et al.* (2017) reported that chlorantraniliprole exhibited high levels of toxicity against *H. armigera* moths with a mortality of 86.67 per cent, during 24 h period at the concentration of 1 mg a.i. per *l*. Su *et al.* (2017) observed that the LC₅₀ values of chlorantraniliprole for early and later instar *Pieris rapae* larvae were 7.92 and 11.34 mg per *l* by contact toxicity, respectively and 0.95 and 4.32 mg per *l* through ingestion, respectively. Reddy and Bhamare (2016) illustrated that *E. vittella* population from different locations of Marathwada region registered variations in susceptibility to chlorantraniliprole 18.5% SC with the resistance ratios of 1.30- to 2.1-fold.

4.2 Chlorpyrifos 20% EC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on the degrees of resistance developed in *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to chlorpyrifos 20% EC are presented in Table 3 and depicted in Fig. 3. The results of comparison of LC₅₀ values in different populations of *L. orbonalis* revealed that different populations had diverse levels of resistance. The LC₅₀ values for larvae of *L. orbonalis* exposed to chlorpyrifos 20% EC ranged from 0.00799 to 0.00589 ml per *l*. The Solapur population recorded a maximum LC₅₀ value to

chlorpyrifos 20% EC (0.00799 ml per *l*) followed by populations from Satara (0.00796 ml per *l*), Nashik (0.00709 ml per *l*), Pune (0.00676 ml per *l*), Sangli (0.00624 ml per *l*), Kolhapur (0.00603 ml per *l*), Ahmednagar (0.00593 ml per *l*) and Osmanabad (0.00589 ml per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to chlorpyrifos 20% EC was 0.00163 ml per *l*.

The resistance ratio of chlorpyrifos 20% EC was found to be highest in *L. orbonalis* population of Solapur (4.90-fold) followed by Satara (4.88-fold), Nashik (4.35-fold), Pune (4.15-fold), Sangli (3.83-fold), Kolhapur (3.70-fold), Ahmednagar (3.64-fold) and Osmanabad (3.61-fold). There was 1.36-fold difference in LC₅₀ values of Solapur and Osmanabad strains among the field populations. The result showed that 8 of 8 field populations (100 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Solapur, Satara, Nashik, Pune, Sangli, Kolhapur, Ahmednagar and Osmanabad evidenced decreased susceptibility to chlorpyrifos 20% EC.

These results coincided with the findings of Kate (2018) who detected development of resistance to chlorpyrifos 20% EC in *L. orbonalis* populations collected from Marathwada region with varied levels of resistance (4.2- to 5.4-fold). Shirale *et al.* (2017) found that *L. orbonalis* populations exhibited widespread resistance to chlorpyrifos (22.17-63.14-fold). Ranjith Kumar (2014) found that among the populations of *L. orbonalis*, Bangalore population recorded a maximum LC₅₀ value (240.00 and 249.83 ppm during 2009-10 and 2010-11, respectively) and resistance ratio (1.20- and 1.18-fold during 2009-10 and 2010-11, respectively) to chlorpyrifos.

Table 3: Chlorpyrifos 20% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.00593	0.00191	0.01010	0.27517	0.769 ± 0.252	0.0541	3.64
2	Kolhapur	0.00603	0.00137	0.01097	0.49551	0.669 ± 0.249	0.0274	3.70
3	Nashik	0.00709	0.00279	0.01174	0.29514	0.791 ± 0.251	0.0832	4.35
4	Pune	0.00676	0.00218	0.01169	0.39093	0.727 ± 0.250	0.0588	4.15
5	Sangli	0.00624	0.00209	0.01059	0.29357	0.766 ± 0.251	0.2081	3.83
6	Satara	0.00796	0.00294	0.01381	0.47596	0.731 ± 0.249	0.0604	4.88
7	Solapur	0.00799	0.00407	0.01240	0.20229	0.913 ± 0.254	0.0720	4.90
8	Osmanabad	0.00589	0.00152	0.01046	0.38739	0.705 ± 0.250	0.2303	3.61
9	Susceptible	0.00163	0.00008	0.00387	0.08582	0.745 ± 0.271	0.1297	-

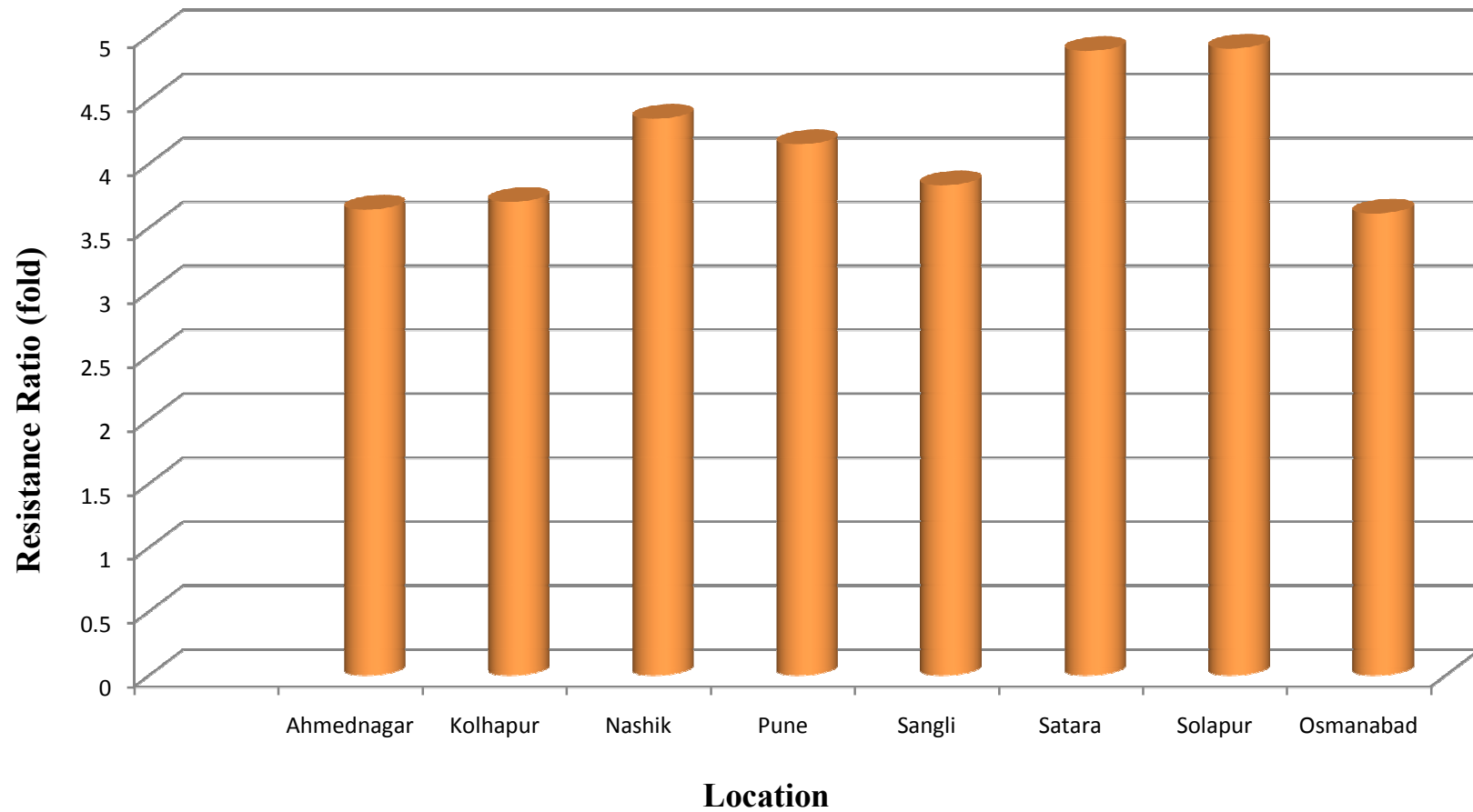


Fig. 3. Chlorpyrifos 20% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

The present investigation also gets the support from the findings of Sreelakshmi *et al.* (2017) who showed that LC₅₀ values of chlorpyrifos in the population of *S. litura* collected from Aleppy, Pathanamthitta and Thiruvananthapuram were 0.64, 1.68 and 3.93 ppm after 48 hours of treatment, respectively and the corresponding resistant ratios were 1, 6.14 and 2.62-fold, respectively. Ramya *et al.* (2016) evidenced that the population of *P. xylostella* exhibited resistance to chlorpyrifos with maximum of 276-fold variation and LC₅₀ ranging from 14 to 3866.9 ppm. Agboyi *et al.* (2016) revealed that *P. xylostella* populations from Dapaong, Kara and Cotonou noticed resistant to chlorpyrifos ethyl with resistant ratios varied from 5 to 15-fold at LC₅₀ level and 9 to 885-fold at LC₉₀ level. Qayyum *et al.* (2015) reported that resistance levels in *H. armigera* ranged from 22 to 87-fold for chlorpyrifos. Hussain *et al.* (2015) revealed that the resistance for chlorpyrifos was low in *H. armigera* (RR = 3.5 to 9.6). Aruna Sri *et al.* (2014) evidenced that Guntur and Prakasam population of *S. litura* developed 6.3 and 5.4-fold and; 5.7 and 2.6-fold resistance to chlorpyrifos during *Kharif* 2007 and 2008, respectively. Hussain *et al.* (2014) noticed that *H. armigera* developed resistance against chlorpyrifos with variation in resistance ratios of 3.48 to 9.62-fold. Ishtiaq *et al.* (2012) revealed that field population of *S. exigua* from Lodhran developed resistance to chlorpyrifos with resistance ratio of 92-fold. Verma *et al.* (2012) proved that the indoxacarb-selected strain of *E. vittella* developed low level of cross resistance against chlorpyrifos (3.05-fold). Ishtiaq *et al.* (2011) demonstrated that resistance ratios of Pakistani population of *S. exigua* ranged from 20-134-fold for chlorpyrifos. Saleem *et al.* (2008) revealed that *S. litura* populations recorded the resistance ratios in the range of 18- to 421-fold for chlorpyrifos.

4.3 Cyantraniliprole 10.26% OD resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on the degrees of resistance acquired by *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to cyantraniliprole 10.26% OD are presented in Table 4 and depicted in Fig. 4. The results of comparison of LC₅₀ values in different populations revealed that different populations of *L. orbonalis* had varied levels of resistance. LC₅₀ values for larvae of *L. orbonalis* exposed to cyantraniliprole 10.26% OD ranged from 0.00371 to 0.00179 ml per *l*. The Kolhapur population recorded maximum LC₅₀ value (0.00371 ml per *l*) to cyantraniliprole 10.26% OD followed by the populations from Nashik (0.00354 ml per *l*), Satara (0.00316 ml per *l*), Sangli (0.00311 ml per *l*), Pune (0.00309 ml per *l*), Ahmednagar (0.00260 ml per *l*), Osmanabad (0.00255 ml per *l*) and Solapur (0.00179 ml per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to cyantraniliprole 10.26% OD was 0.00137 ml per *l*.

The highest resistance ratio was exhibited to cyantraniliprole 10.26% OD in *L. orbonalis* population of Kolhapur (2.71-fold) followed by Nashik (2.58-fold), Satara (2.31-fold), Sangli (2.27-fold), Pune (2.25-fold), Ahmednagar (1.90-fold), Osmanabad (1.86-fold) and Solapur (1.31-fold). The variations of resistance (2.07-fold between Kolhapur and Solapur populations) observed among the field populations assayed. The result showed that 8 of 8 field populations (100 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Kolhapur, Nashik, Satara, Sangli, Pune, Ahmednagar, Osmanabad and Solapur expressed susceptibility to cyantraniliprole 10.26% OD.

Table 4: Cyantraniliprole 10.26% OD resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.00260	0.00013	0.00601	0.15810	0.718 ± 0.266	0.3441	1.90
2	Kolhapur	0.00371	0.00031	0.00779	0.24784	0.702 ± 0.259	0.1813	2.71
3	Nashik	0.00354	0.00064	0.00676	0.10490	0.870 ± 0.272	0.4748	2.58
4	Pune	0.00309	0.00024	0.00668	0.17021	0.736 ± 0.264	0.2457	2.25
5	Sangli	0.00311	0.00016	0.00699	0.23490	0.682 ± 0.260	0.1495	2.27
6	Satara	0.00316	0.00056	0.00613	0.08285	0.904 ± 0.277	0.1096	2.31
7	Solapur	0.00179	0.00006	0.00456	0.08843	0.757 ± 0.278	0.0883	1.31
8	Osmanabad	0.00255	0.00028	0.00542	0.08197	0.850 ± 0.278	0.0772	1.86
9	Susceptible	0.00137	0.00004	0.00370	0.05168	0.812 ± 0.295	0.2353	-

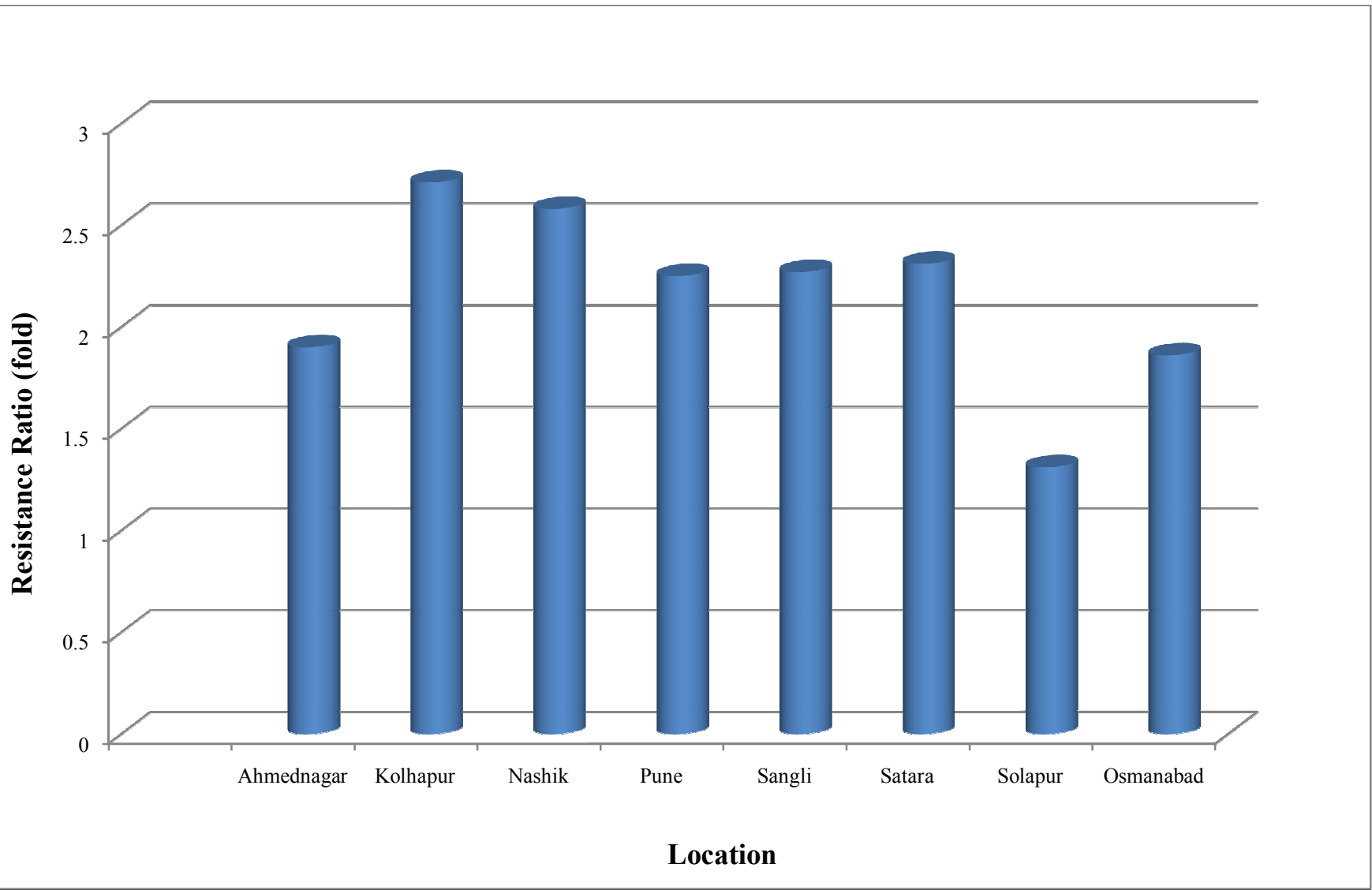


Fig. 4. Cyntraniliprole 10.26% OD resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

These results are in concurrence with the findings of Kate (2018) who exhibited that all the populations of *L. orbonalis* collected from Marathwada indicated susceptibility to cyantraniliprole 10.26% OD with varied levels of resistance (1.24- to 1.42-fold). Sharma *et al.* (2018) evidenced that LT_{50} values of cyantraniliprole against *L. orbonalis* were 4.47 and 4.69 days during 2015 and 2016, respectively. Kodandaram *et al.* (2017) evidenced that cyantraniliprole was 5.23 times more toxic to *L. orbonalis* as compared to flubendiamide. Large variation in the susceptibility of *L. orbonalis* to cyantraniliprole was observed in span of two years with increase in the LC_{50} values from 0.062 to 0.085 mg a.i. per *l*. Kodandaram *et al.* (2015) indicated that cyantraniliprole was highly toxic to the third instar larvae of *L. orbonalis* and recorded LC_{50} value of 0.62 ppm. Kodandaram *et al.* (2013) revealed that LC_{50} value of cyantraniliprole against *L. orbonalis* was 0.000062 per cent (0.62 ppm).

Similar trend in results were obtained by Shanmugapriya *et al.* (2019) who indicated that the LC_{50} values and resistant ratios of the different population of *P. xylostella* collected from Coimbatore, Ooty, Oddanchatram, Krishnagiri and Theni for Cyantraniliprole were 0.010, 0.012, 0.014, 0.011 and 0.011 mg per ml and; 1.43, 1.71, 2.00, 2.43, and 1.57-folds, respectively. Meghana *et al.* (2018) revealed that the LC_{50} value for cyantraniliprole 10.26 OD in Bengaluru, Kolar and Chikkaballapura populations of *P. xylostella* were 4.43, 4.48 and 4.48 μ g a.i. ml per *l*, respectively. Karjule *et al.* (2017) reported that *H. armigera* populations registered susceptibility to cyantraniliprole with resistance ratios varied from 1.74- to 2.10-fold. Bird (2016a) observed that intraspecific variation in cyantraniliprole susceptibility amongst field strains was 9.3-fold in topical bioassays (LC_{50} =28 mg per *l*) and 2.6-fold in ingestion bioassays (LC_{50} = 0.065 mg per *l*). Cyantraniliprole was

recorded >400-fold more toxic when administered orally than by contact. Reddy and Bhamare (2016) documented that *E. vittella* population collected from different locations of Marathwada region registered variations in susceptibility to cyantraniliprole with variation in resistance ratios from 1.40- to 1.94-fold.

4.4 Cypermethrin 25% EC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on the degrees of resistance acquired by *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to cypermethrin 25% EC are presented in Table 5 and depicted in Fig. 5. The results of comparison of LC₅₀ values in different populations revealed that different populations of *L. orbonalis* had varied levels of resistance. LC₅₀ values for larvae of *L. orbonalis* exposed to cypermethrin 25% EC ranged from 0.00632 to 0.00405 ml per *l*. The Kolhapur population recorded a maximum LC₅₀ value to cypermethrin 25% EC (0.00632 ml per *l*) followed by populations from Pune (0.00598 ml per *l*), Satara (0.00540 ml per *l*), Solapur (0.00535 ml per *l*), Nashik (0.00511 ml per *l*), Sangli (0.00478 ml per *l*), Osmanabad (0.00423 ml per *l*) and Ahmednagar (0.00405 ml per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to cypermethrin 25% EC was 0.00127 ml per *l*.

The resistance ratio of cypermethrin 25% EC was found to be highest in *L. orbonalis* population of Kolhapur (4.98-fold) followed by Pune (4.71-fold), Satara (4.25-fold), Solapur (4.21-fold), Nashik (4.02-fold), Sangli (3.76-fold), Osmanabad (3.33-fold) and Ahmednagar (3.19-fold). There was 1.56-fold difference in LC₅₀ values of Kolhapur and Ahmednagar strains among the field populations. The result showed that 8 of 8 field populations (100 per cent) of *L. orbonalis* infesting

brinjal collected from Western Maharashtra region i.e. Kolhapur, Pune, Satara, Solapur, Nashik, Sangli, Osmanabad and Ahmednagar evidenced decreased susceptibility to cypermethrin 25% EC.

The present results are in harmony with the findings of Kate (2018) who detected development of insecticide resistance in *L. orbonalis* collected from Marathwada region and exhibited that all the populations of *L. orbonalis* indicated decreased susceptibility to cypermethrin 25% EC with varied levels of resistance (3.18- to 3.72-fold). Murali *et al.* (2017) reported that Belagavi, Bengaluru and Koppal populations of *L. orbonalis* were most susceptible to cypermethrin with LC₅₀ values in the range of 0.04 to 0.13 ml per l. Kodandaram *et al.* (2015) noticed that the LC₅₀ value of *L. orbonalis* for cypermethrin was 4057 ppm. Ranjith Kumar (2014) revealed that *L. orbonalis* population of Raichur (42.00 ppm and 1.20-fold during 2009-10) and Hyderabad (58.60 ppm and 1.33-fold during 2010-11) recorded a maximum LC₅₀ values and resistance ratios to cypermethrin.

More or less analogous results were obtained by Sreelakshmi *et al.* (2017) who revealed that LC₅₀ values of cypermethrin in the population of *S. litura* collected from Aleppy, Pathanamthitta and Thiruvananthapuram were 1.98, 2.67 and 12.83 ppm after 48 hours of treatment, respectively. Karuppaiah *et al.* (2017) studied carboxylesterase-mediated insecticide resistance in *S. litura* with three different populations from Varanasi, Delhi and Sonapat and found that the LC₅₀ values of cypermethrin were 210, 220 and 100 ppm, respectively. The trend of cypermethrin toxicity was Sonapat > Delhi > Varanasi population. The Delhi and Sonapat field population registered 2.1- and 2.2-fold higher LC₅₀ for cypermethrin than that of the Varanasi susceptible population.

Table 5: Cypermethrin 25% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.00405	0.00137	0.00701	0.23750	0.725 ± 0.249	0.0330	3.19
2	Kolhapur	0.00632	0.00295	0.01164	0.39710	0.713 ± 0.247	0.1131	4.98
3	Nashik	0.00511	0.00158	0.00985	0.56871	0.626 ± 0.246	0.0767	4.02
4	Pune	0.00598	0.00269	0.01083	0.37417	0.713 ± 0.247	0.0498	4.71
5	Sangli	0.00478	0.00184	0.00832	0.28883	0.719 ± 0.248	0.1378	3.76
6	Satara	0.00540	0.00242	0.00933	0.28150	0.746 ± 0.248	0.4932	4.25
7	Solapur	0.00535	0.00223	0.00946	0.33082	0.715 ± 0.248	0.0357	4.21
8	Osmanabad	0.00423	0.00104	0.00794	0.45861	0.630 ± 0.247	0.0428	3.33
9	Susceptible	0.00127	0.00006	0.00285	0.09556	0.683 ± 0.260	0.1516	-

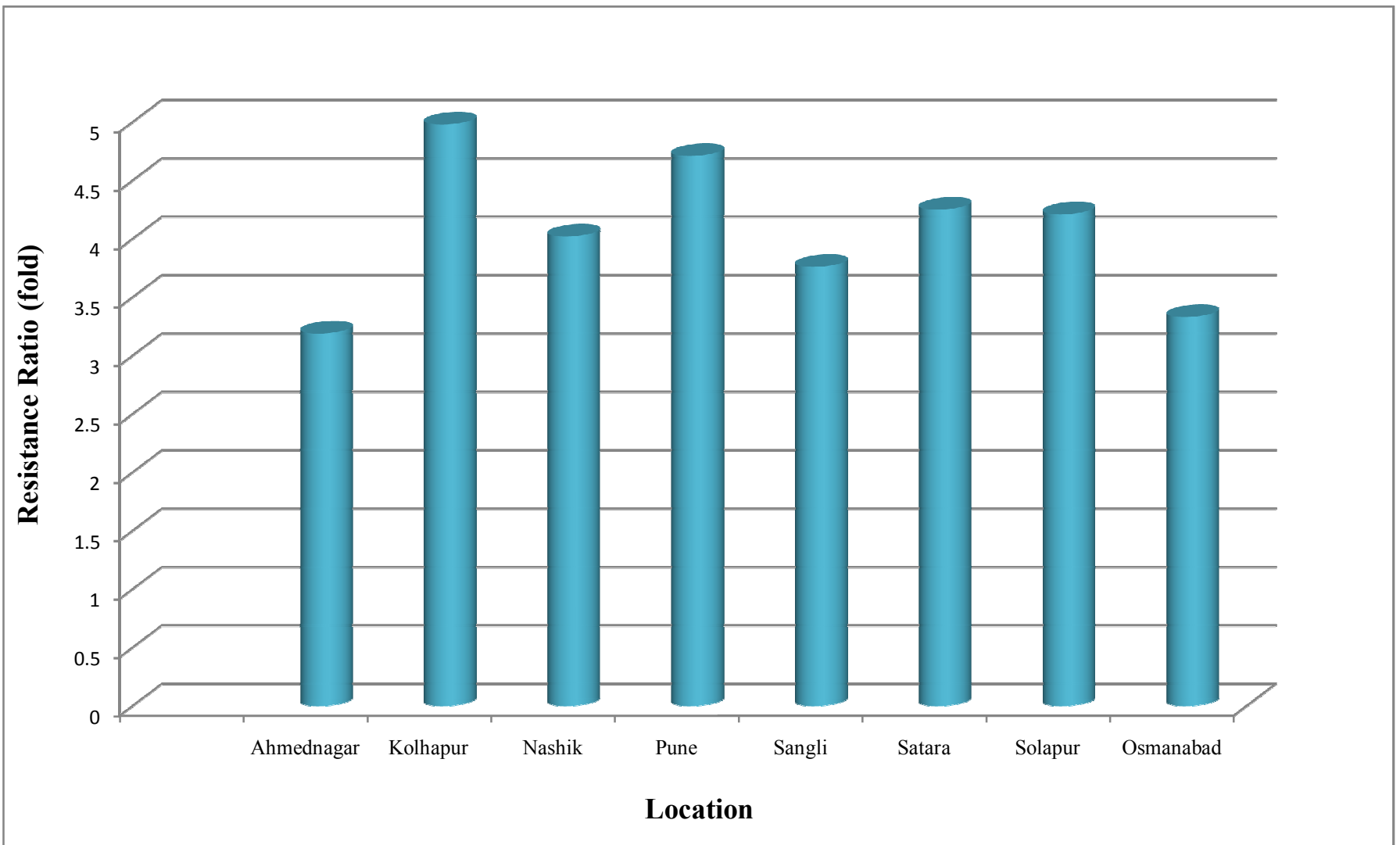


Fig. 5. Cypermethrin 25% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Ramya *et al.* (2016) evidenced that *P. xylostella* showed moderate to high level of resistance to cypermethrin where the Oddanchatram population noticed most resistant (108-fold). The resistance to cypermethrin varied from 108-fold with LC₅₀ ranging from 22 to 2993 ppm. Jat *et al.* (2016) found that LC₅₀ value of cypermethrin was 0.04125 per cent against second instar larvae of *H. armigera*. Qayyum *et al.* (2015) reported that the resistance ratios (RRs) for cypermethrin in *H. armigera* varied from 3 to 69-fold. Muhammad *et al.* (2015) showed that the baseline susceptibility value of *E. vittella* to cypermethrin was 1.24. Aruna Sri *et al.* (2014) revealed that Guntur and Prakasam populations of *S. litura* developed 16.2 and 14.4-folds and; 15.4 and 11.3-fold resistance at LD₅₀ to cypermethrin during *Kharif* 2007 and 2008, respectively. Ishtiaq *et al.* (2012a) evidenced that *S. exigua* developed 66-fold resistant to cypermethrin.

Similarly, Ishtiaq *et al.* (2012b) showed that Pakistani populations of *S. exigua* acquired 12 to 136-fold resistance to cypermethrin. Kang *et al.* (2012) revealed that cypermethrin was least effective against Mansa and Muktsar populations of *E. vittella* with LD₅₀ values of 0.325 and 0.173 µg per larvae, respectively. Ishtiaq and Saleem (2011) demonstrated that *S. exigua* of Multan developed very low level of resistance to cypermethrin (RF=6), whereas the D.G. Khan population of *S. exigua* acquired very high level of resistant to cypermethrin (RF=132). Ahmad and Arif (2008) revealed that among the pyrethroids, resistance was generally low to zeta-cypermethrin and moderate to high or very high to cypermethrin, deltamethrin, esfenvalerate, bifenthrin and lambda-cyhalothrin in field populations of *E. vittella* at Multan in Pakistan.

4.5 Dimethoate 30% EC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on the degrees of resistance acquired by *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to dimethoate 30% EC are presented in Table 6 and depicted in Fig. 6. The results of comparison of LC_{50} values in different populations of *L. orbonalis* revealed that different populations had diverse levels of resistance. LC_{50} values for larvae of *L. orbonalis* exposed to dimethoate 30% EC ranged from 0.01224 to 0.01780 ml per *l*. The Nashik population recorded a maximum LC_{50} value to dimethoate 30% EC (0.01780 ml per *l*) followed by populations from Satara (0.01588 ml per *l*), Solapur (0.01558 ml per *l*), Kolhapur (0.01459 ml per *l*), Osmanabad (0.01414 ml per *l*), Ahmednagar (0.01270 ml per *l*), Pune (0.01259 ml per *l*) and Sangli (0.01224 ml per *l*). However, LC_{50} value of susceptible strain of *L. orbonalis* to dimethoate 30% EC was 0.00292 ml per *l*.

The resistance ratio of dimethoate 30% EC was found to be highest in *L. orbonalis* population of Nashik (6.10-fold) followed by Satara (5.44-fold), Solapur (5.34-fold), Kolhapur (5.00-fold), Osmanabad (4.84-fold), Ahmednagar (4.35-fold), Pune (4.31-fold) and Sangli (4.19-fold). There was 1.45-fold difference in LC_{50} values of Nashik and Sangli strains among the field populations. The result showed that 3 of 8 field populations (37.5 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Nashik, Satara and Solapur showed low level of resistance to dimethoate 30% EC. However remaining 5 of 8 field populations (62.5 per cent) of *L. orbonalis* collected from Kolhapur, Omanabad, Ahmednagar, Pune and Sangli exhibited decreased susceptibility to dimethoate 30% EC.

Table 6: Dimethoate 30% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.01270	0.00285	0.02285	0.60210	0.765 ± 0.255	0.0370	4.35
2	Kolhapur	0.01459	0.00410	0.02524	0.61625	0.788 ± 0.255	0.2425	5.00
3	Nashik	0.01780	0.00572	0.03029	0.82551	0.769 ± 0.252	0.0541	6.10
4	Pune	0.01259	0.00359	0.02171	0.41476	0.844 ± 0.259	0.0669	4.31
5	Sangli	0.01224	0.00148	0.02389	1.08168	0.658 ± 0.252	0.0298	4.19
6	Satara	0.01588	0.00643	0.02534	0.38342	0.927 ± 0.259	0.0560	5.44
7	Solapur	0.01558	0.00412	0.02729	0.80108	0.749 ± 0.253	0.5404	5.34
8	Osmanabad	0.01414	0.00106	0.02865	2.2119	0.584 ± 0.248	0.0045	4.84
9	Susceptible	0.00292	0.00002	0.00872	0.20874	0.691 ± 0.279	0.2408	-

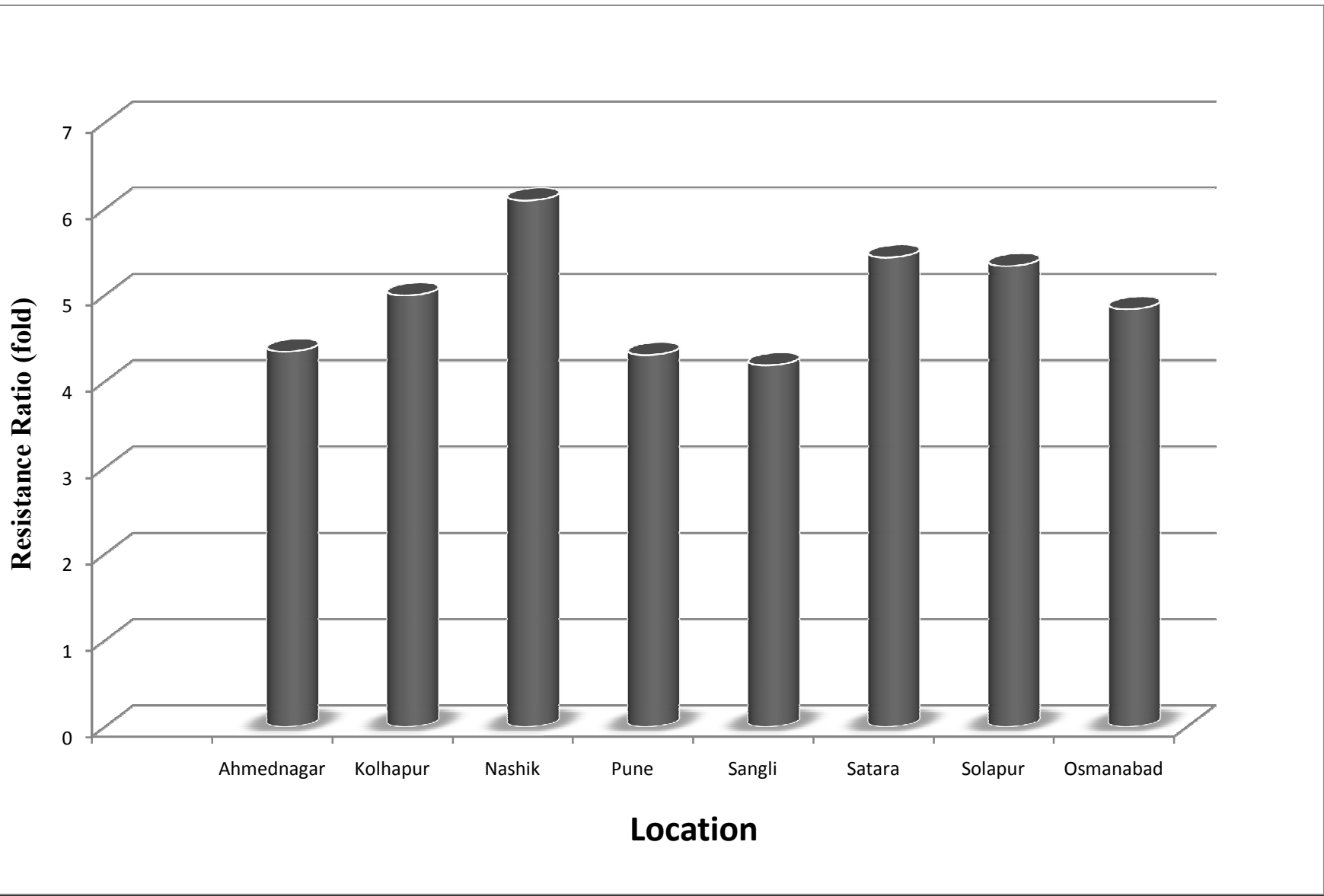


Fig. 6. Dimethoate 30% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

These results coincide with the findings of Kate (2018) who exhibited that populations of *L. orbonalis* treated with dimethoate 30% EC showed varied level of resistance (4.80- to 5.80-fold). However, Kodandaram *et al.* (2015) indicated lower efficacy of dimethoate against *L. orbonalis*.

4.6 Emamectin benzoate 5% SG resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on degrees of resistance developed in *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to emamectin benzoate 5% SG are presented in Table 7 and depicted in Fig. 7. The results of comparison of LC₅₀ values in different populations revealed that different populations of *L. orbonalis* had varied levels of resistance. LC₅₀ values for larvae of *L. orbonalis* exposed to emamectin benzoate 5% SG ranged from 0.00030 to 0.00051 g per *l*. The Solapur population evidenced a maximum LC₅₀ value to emamectin benzoate 5% SG (0.00051 g per *l*) followed by populations from Nashik (0.00047 g per *l*), Kolhapur (0.00045 g per *l*), Satara (0.00044 g per *l*), Sangli (0.00043 g per *l*), Ahmednagar (0.00032 g per *l*), Pune (0.00031 g per *l*) and Osmanabad (0.00030 g per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to emamectin benzoate 5% SG was 0.00021 g per *l*.

L. orbonalis population of Solapur noticed highest resistance ratio to emamectin benzoate 5% SG (2.43-fold) followed by Nashik (2.24-fold), Kolhapur (2.14-fold), Satara (2.10-fold), Sangli (2.05-fold), Ahmednagar (1.52-fold), Pune (1.48-fold) and Osmanabad (1.43-fold). The variations of resistance (1.70-fold between Solapur and Osmanabad populations) existed among the field populations assayed. The result showed that 8 of 8 field populations (100 per cent) of *L. orbonalis*

infesting brinjal collected from Western Maharashtra region i.e. Solapur, Nashik, Kolhapur, Satara, Sangli, Ahmednagar, Pune and Osmanabad, evidenced susceptibility to emamectin benzoate 5% SG.

The present results are in agreement with the findings of Kate (2018) who exhibited that all the populations of *L. orbonalis* collected from Marathwada region indicated susceptibility to emamectin benzoate 5% SG with varied level of resistance (2.33- to 2.75-fold). Munje *et al.* (2015) stated that *L. orbonalis* exhibited variations in toxicity in terms of LC₅₀ for emamectin benzoate (0.277-0.351 ppm). Ranjith Kumar (2014) evidenced that Bangalore population recorded a maximum LC₅₀ values (4.20 and 4.41 ppm) and higher degrees of resistance (1.95 and 1.97-fold) to emamectin benzoate during 2009-10 and 2010-11. Botre *et al.* (2014) illustrated that the LC₅₀ values of emamectin benzoate for field strains of *L. orbonalis* differed from 0.277 to 0.351 ppm. Kaur *et al.* (2014) revealed that the LC₅₀ values and toxicity ratios of emamectin benzoate against Amritsar, Malerkotla and Hoshiarpur populations of *L. orbonalis* were 0.49, 0.061 and 0.24 ppm and; 3.26, 6.72 and 3.37-fold, respectively.

More or less similar results were obtained by Sharma *et al.* (2019) who revealed that the LC₅₀ value of emamectin benzoate was computed to be 0.020 and 0.00007 ppm against third instar larva of *S. litura* and *P. brassicae*, respectively. Meghana *et al.* (2018) exhibited that LC₅₀ values for Bengaluru, Kolar and Chikkaballapura populations were lowest for emamectin benzoate 5 SG (3.13, 5.86 and 3.42 µg a.i. ml per l). Sattar *et al.* (2017) revealed that emamectin benzoate recorded minimum LC₅₀ value (1.650 mg per l) against *H. armigera*. Karjule *et al.* (2017) noticed that *H. armigera* populations indicated susceptibility to emamectin benzoate 5% SG with variation in resistance ratios of 2.09- to 2.54-fold.

Table 7: Emamectin benzoate 5% SG resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.00032	0.00001	0.00078	0.02926	0.655 ± 0.261	0.0277	1.52
2	Kolhapur	0.00045	0.00008	0.00086	0.01501	0.842 ± 0.267	0.0673	2.14
3	Nashik	0.00047	0.00006	0.00095	0.02593	0.738 ± 0.260	0.1131	2.24
4	Pune	0.00031	0.00001	0.00075	0.02670	0.661 ± 0.262	0.0878	1.48
5	Sangli	0.00043	0.00002	0.00095	0.03750	0.661 ± 0.257	0.0994	2.05
6	Satara	0.00044	0.00009	0.00082	0.01184	0.898 ± 0.271	0.1095	2.10
7	Solapur	0.00051	0.00002	0.00111	0.06327	0.611 ± 0.253	0.2886	2.43
8	Osmanabad	0.00030	0.00001	0.00072	0.02349	0.675 ± 0.265	0.4243	1.43
9	Susceptible	0.00021	0.00000	0.00058	0.01611	0.681 ± 0.271	0.2666	-

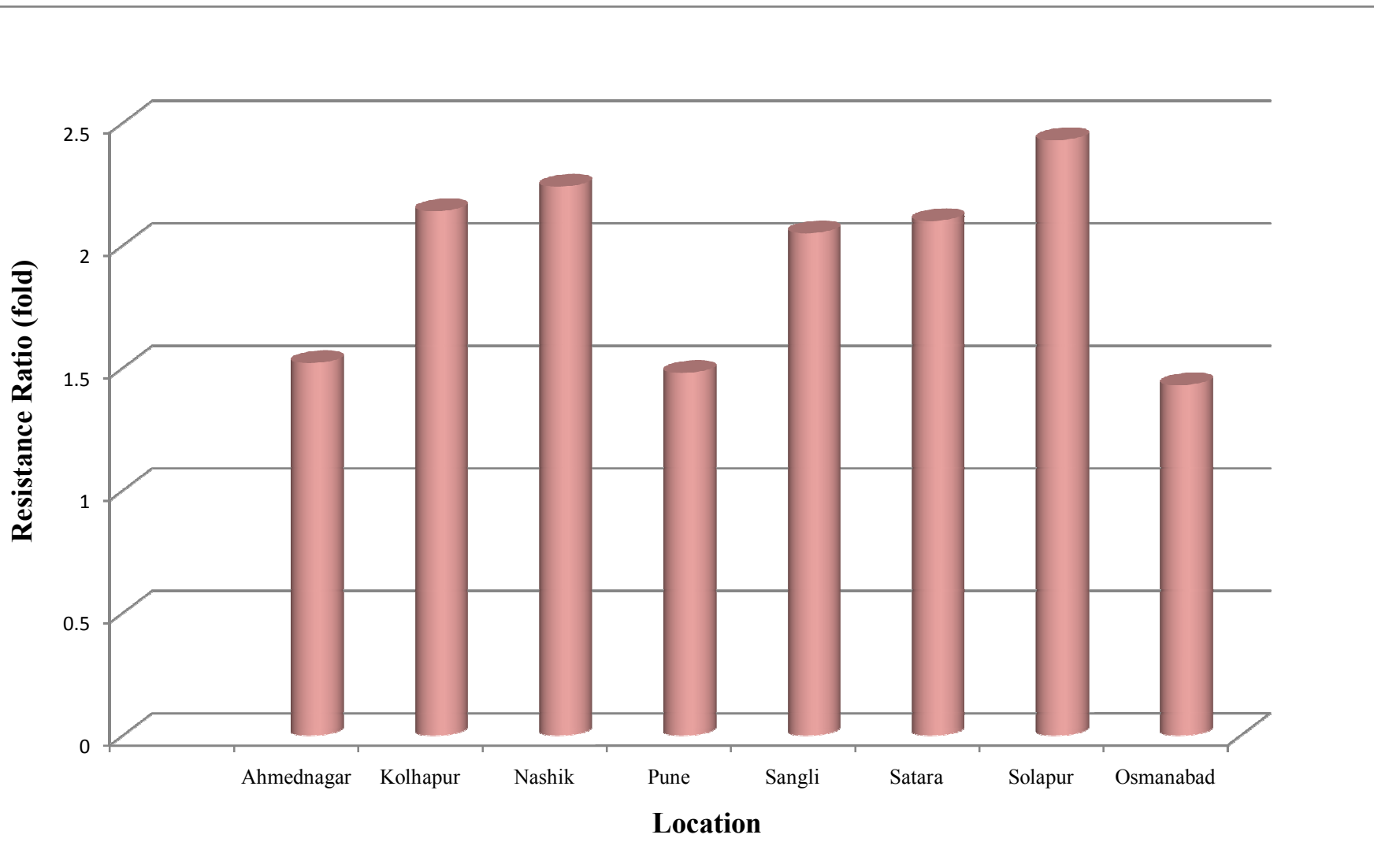


Fig. 7. Emamectin benzoate 5% SG resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Similarly, Bird *et al.* (2017) could not detect resistance in *H. armigera* populations of Australia to emamectin benzoate. Liu *et al.* (2017) exhibited high level of toxicity of emamectin benzoate against *H. armigera* moths with 91.1 per cent mortality. Similarly, Pan *et al.* (2017) showed susceptibility in field population of *H. armigera* from Qiuxian County to emamectin benzoate. Reddy and Bhamare (2016) exhibited that *E. vittella* population collected from different locations of Marathwada region registered variations in susceptibility to emamectin benzoate 5% SG with resistance ratios of 2.37- to 1.56-fold. Jat *et al.* (2016) found that emamectin benzoate 5% SG @ 1×10^{-7} to 1×10^{-9} per cent concentrations recorded 100 per cent mortality in 2nd instar larvae of *H. armigera* and LC₅₀ values for 3rd instar larvae was 0.0000000045 per cent.

Hussain *et al.* (2015) revealed that resistance was low for emamectin benzoate (RR = 1.7 to 5.2) in *H. armigera*. Deepa (2015) revealed that larval population of *H. armigera* collected from Mahaboobnagar recorded the LC₅₀ values to the tune of 0.011, 0.017 and 0.025 mg per *l* and LC₉₀ values to the extent of 0.37, 0.51 and 0.87 mg per *l* at 24, 48 and 72 hours after treatment, respectively for emamectin benzoate. On comparing with baseline data the resistance factors obtained were 1.1, 1.7 and 2.5 (emamectin benzoate) at 24, 48 and 72 hours after treatment, respectively. Bird (2015) revealed that emamectin benzoate had the highest toxicity against *H. armigera* with a median lethal concentration (LC₅₀) of 0.01 µg per ml diet (n=20 strains). Variation in susceptibility amongst field strains was 2.3-fold for emamectin benzoate.

4.7 Fenprothrin 30% EC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on degrees of resistance developed in *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to fenprothrin 30% EC are presented in Table 8 and depicted in Fig. 8. The results of comparison of LC₅₀ values in different populations revealed that different populations of *L. orbonalis* had diverse levels of resistance. LC₅₀ values for larvae of *L. orbonalis* exposed to fenprothrin 30% EC ranged from 0.02776 to 0.04109 ml per *l*. The Ahmednagar population evidenced a maximum LC₅₀ value to fenprothrin 30% EC (0.04109 ml per *l*) followed by populations from Solapur (0.03880 ml per *l*), Pune (0.03748 ml per *l*), Sangli (0.03714 ml per *l*), Satara (0.03443 ml per *l*), Nashik (0.03269 ml per *l*), Osmanabad (0.02881 ml per *l*) and Kolhapur (0.02776 ml per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to fenprothrin 30% EC was 0.01053 ml per *l*.

L. orbonalis population of Ahmednagar noticed highest resistance ratio to fenprothrin 30% EC (3.90-fold) followed by Solapur (3.68-fold), Pune (3.56-fold), Sangli (3.53-fold), Satara (3.27-fold), Nashik (3.10-fold), Osmanabad (2.74-fold) and Kolhapur (2.64- fold). The variations of resistance (1.48-fold between Ahmednagar and Kolhapur populations) existed among the field populations assayed. The result showed that 6 of 8 field populations (75 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Ahmednagar, Solapur, Pune, Sangli, Satara and Nashik showed decreased susceptibility to fenprothrin 30% EC. However remaining 2 of 8 field populations (25 per cent) of *L. orbonalis* collected from Osmanabad and Kolhapur exhibited susceptibility to fenprothrin 30% EC.

Table 8: Fenpropathrin 30% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.04109	0.00934	0.07480	3.37851	0.669 ± 0.249	0.0274	3.90
2	Kolhapur	0.02776	0.00431	0.05261	1.91100	0.697 ± 0.253	0.2495	2.64
3	Nashik	0.03269	0.00590	0.06068	2.45613	0.683 ± 0.251	0.0679	3.10
4	Pune	0.03748	0.01780	0.05718	0.65251	1.033 ± 0.263	0.0762	3.56
5	Sangli	0.03714	0.01335	0.06121	1.20856	0.847 ± 0.256	0.1365	3.53
6	Satara	0.03443	0.01101	0.05802	1.23492	0.824 ± 0.256	0.5404	3.27
7	Solapur	0.03880	0.00840	0.07072	3.08057	0.675 ± 0.250	0.3582	3.68
8	Osmanabad	0.02881	0.00745	0.05055	1.11320	0.807 ± 0.258	0.4037	2.74
9	Susceptible	0.01053	0.00029	0.02636	1.72079	0.698 ± 0.268	0.0487	-

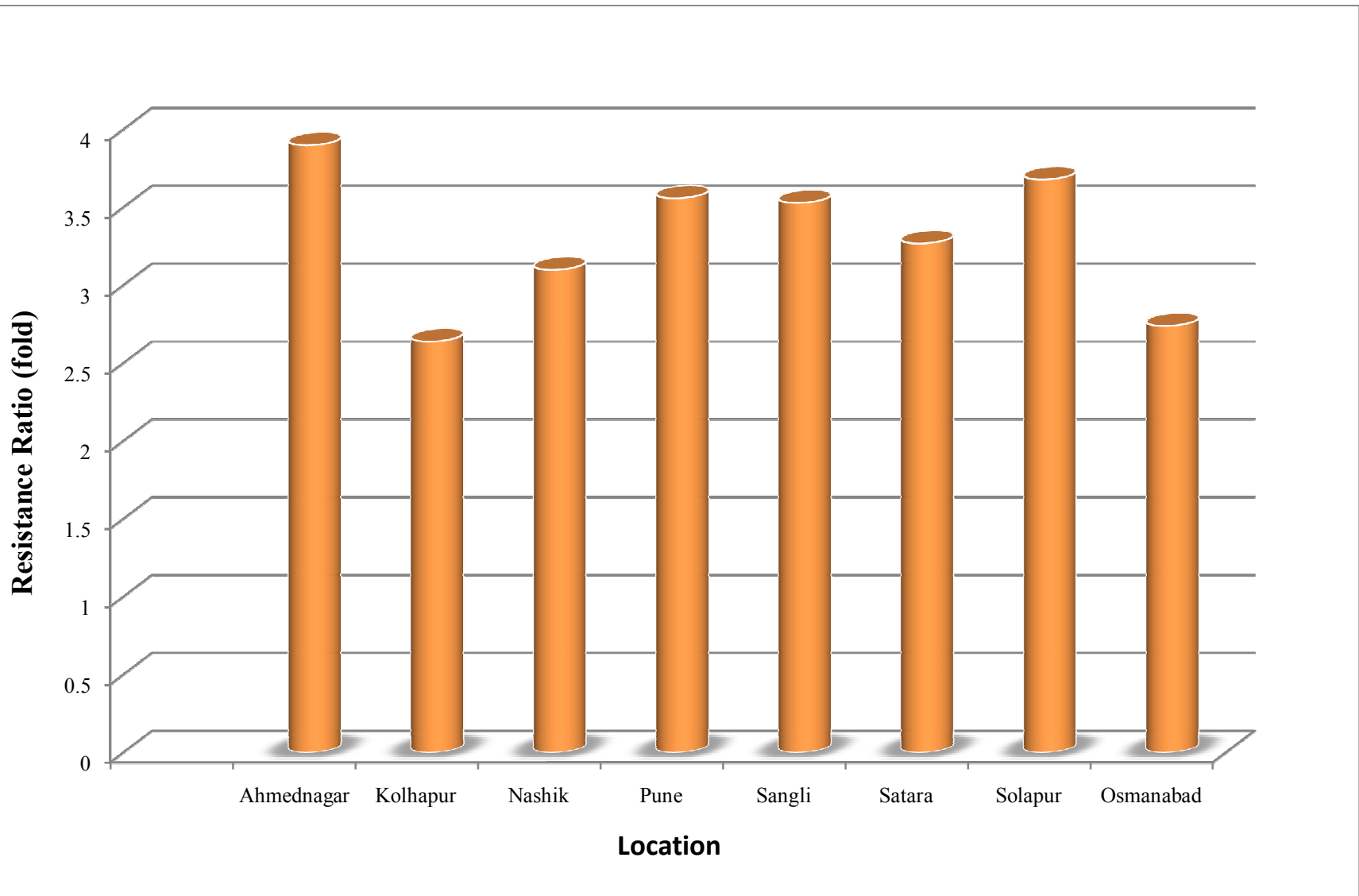


Fig. 8. Fenpropathrin 30% EC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

The present results are in concurrence with the findings of Kate (2018) who exhibited that all the populations of *L. orbonalis* collected from Marathwada region indicated susceptibility to fenpropathrin 30% EC with varied level of resistance (2.51- to 3.00-fold). Murali *et al.* (2017) reported that Belagavi, Bengaluru and Koppal populations of *L. orbonalis* were most susceptible to fenpropathrin (LC_{50} = 0.04 to 0.13 ml per l) and among different populations, Belagavi population was 2.5-fold more resistant to fenpropathrin.

4.8 Lambda-cyhalothrin 5% SC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on degrees of resistance acquired by *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to lambda-cyhalothrin 5% SC are presented in Table 9 and depicted in Fig. 9. The results of comparison of LC_{50} values in different populations revealed that different populations of *L. orbonalis* had diverse levels of resistance. LC_{50} values for larvae of *L. orbonalis* exposed to lambda-cyhalothrin 5% SC ranged from 0.00037 to 0.00057 ml per l. The Nashik population evidenced a maximum LC_{50} value to lambda-cyhalothrin 5% SC (0.00057 ml per l) followed by populations from Solapur (0.00054 ml per l), Sangli (0.00047 ml per l), Pune (0.00045 ml per l), Kolhapur (0.00044 ml per l), Osmanabad (0.00041 ml per l), Ahmednagar (0.00040 ml per l) and Satara (0.00037 ml per l). However, LC_{50} value of susceptible strain of *L. orbonalis* to lambda-cyhalothrin 5% SC was 0.00011 ml per l.

Table 8. Lambda-cyhalothrin 5% SC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.00040	0.00018	0.00064	0.01237	0.860 ± 0.254	0.2973	3.64
2	Kolhapur	0.00044	0.00017	0.00074	0.02190	0.754 ± 0.250	0.0466	4.00
3	Nashik	0.00057	0.00026	0.00100	0.03000	0.745 ± 0.248	0.0432	5.18
4	Pune	0.00045	0.00024	0.00068	0.00898	0.985 ± 0.257	0.0833	4.09
5	Sangli	0.00047	0.00023	0.00074	0.01340	0.880 ± 0.253	0.0127	4.27
6	Satara	0.00037	0.00017	0.00059	0.00995	0.899 ± 0.256	0.0282	3.36
7	Solapur	0.00054	0.00029	0.00085	0.01576	0.874 ± 0.252	0.2472	4.91
8	Osmanabad	0.00041	0.00011	0.00074	0.03486	0.664 ± 0.248	0.1860	3.73
9	Susceptible	0.00011	0.00001	0.00024	0.00531	0.761 ± 0.269	0.0263	-

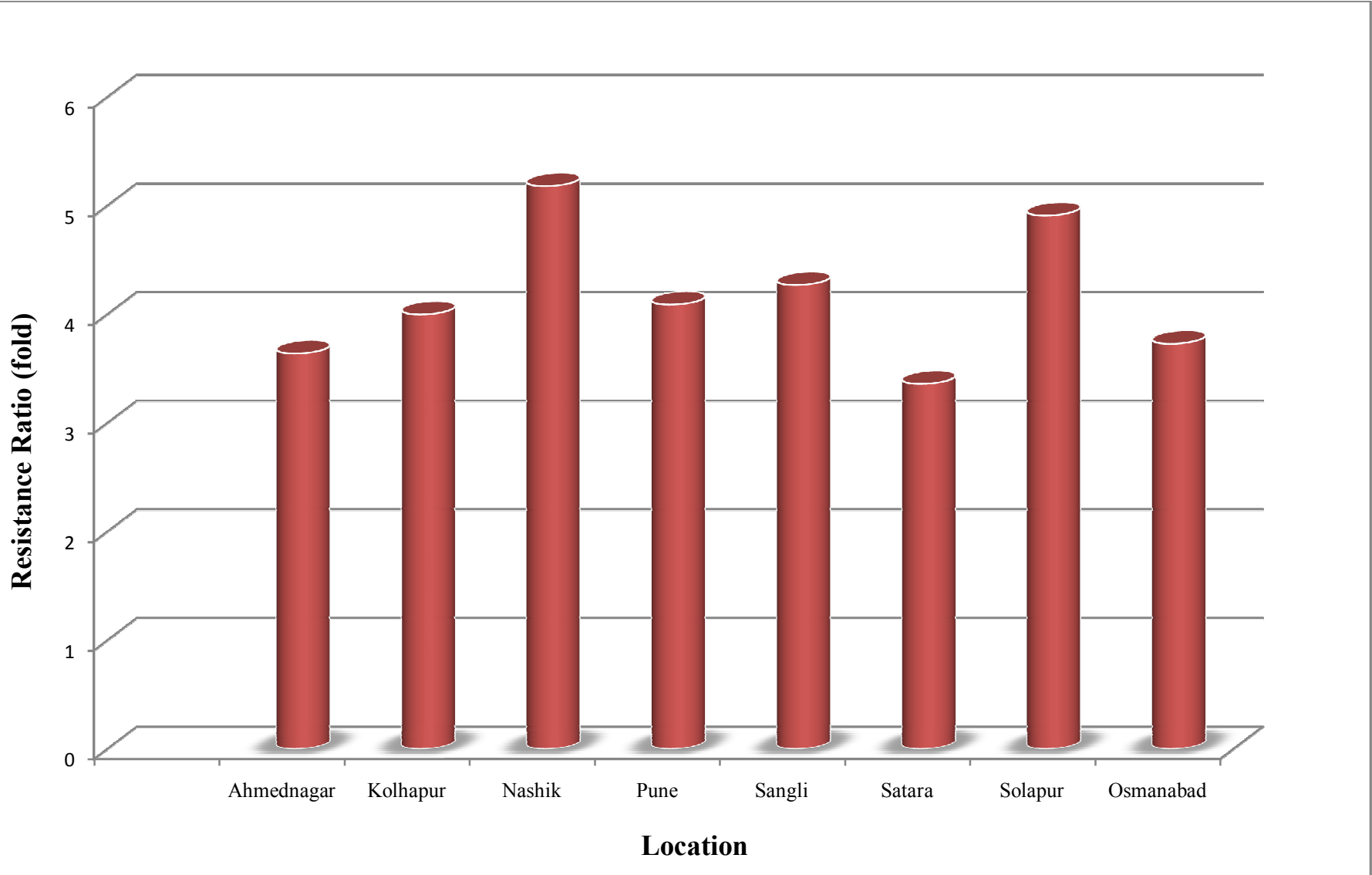


Fig. 9. Lambda cyhalothrin 5% SC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

L. orbonalis population of Nashik noticed highest resistance ratio to lambda-cyhalothrin 5% SC (5.18-fold) followed by Solapur (4.91-fold), Sangli (4.27-fold), Pune (4.09-fold), Kolhapur (4.00-fold), Osmanabad (3.73-fold), Ahmednagar (3.64-fold) and Satara (3.36- fold). The variations of resistance (1.54-fold between Nashik and Satara populations) existed among the field populations assayed. The result showed that 1 of 8 field populations (12.5 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Nashik showed low level of resistance to lambda-cyhalothrin 5% SC. However, remaining 7 of 8 field populations (87.5 per cent) of *L. orbonalis* collected from Solapur, Sangli, Pune, Kolhapur, Osmanabad, Ahmednagar and Satara exhibited decreased susceptibility to lambda-cyhalothrin 5% SC.

The present results are matching with the findings of Sharma *et al.* (2018) who studied residual toxicity of different insecticides against *L. orbonalis* and reported that Persistent Toxicity (PT) values for lambda-cyhalothrin were 355.83 and 344.17 and LT_{50} values were 3.35 and 3.19 days during 2015 and 2016, respectively. Kate (2018) exhibited that populations of *L. orbonalis* treated with lambda-cyhalothrin 5% SC showed varied level of resistance (3.55-fold to 4.21-fold). Murali *et al.* (2017) evidenced that the Kolar population of *L. orbonalis* was found to be most susceptible to λ -cyhalothrin with LC_{50} value of 0.02 ml per *l.* Among different populations, Bengaluru population was 10.5-fold resistant to λ -cyhalothrin.

More or less analogous results were documented by Sreelakshmi *et al.* (2017) who evidenced that the LC_{50} values of lambda-cyhalothrin in the population of *S. litura* collected from Aleppy, Pathanamthitta and Thiruvananthapuram were 3.05, 7.00 and 25.93 ppm

after 48 hours of treatment, respectively. Reddy and Bhamare (2016) revealed that *E. vittella* populations collected from Marathwada developed moderate level of resistance to lambda-cyhalothrin with varied resistance ratios in the range of 7.38-11.63-fold among the populations assayed. Hussain *et al.* (2015) revealed that based on the calculated RRs, the field populations of *H. armigera* were found moderately to highly resistant to lambda-cyhalothrin (RR = 19.6 to 68.2) Hussain *et al.* (2014) showed that the toxicity of lambda-cyhalothrin compared with the Lab-Pk strain was in the range of the 19.6-68.17-fold. Deepa *et al.* (2006) found that the LD₅₀ value of lambda-cyhalothrin for F₁ population of *E. vittella* was 0.00394 µg per larva and LD₉₅ value was 0.0174 µg per larva.

4.9 Thiacloprid 21.7% SC resistance in field population of *Leucinodes orbonalis* (Guenee)

The data on degrees of resistance developed in *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra to thiacloprid 21.7% SC are presented in Table 10 and depicted in Fig. 10. The results of comparison of LC₅₀ values in different populations revealed that different populations of *L. orbonalis* had diverse levels of resistance. LC₅₀ values for larvae of *L. orbonalis* exposed to thiacloprid 21.7% SC ranged from 0.00825 to 0.01514 ml per *l*. The Solapur population evidenced a maximum LC₅₀ value to thiacloprid 21.7% SC (0.01514 ml per *l*) followed by populations from Nashik (0.01343 ml per *l*), Satara (0.01325 ml per *l*), Kolhapur (0.01245 ml per *l*), Ahmednagar (0.01175 ml per *l*), Sangli (0.01007 ml per *l*), Osmanabad (0.00902 ml per *l*) and Pune (0.00825 ml per *l*). However, LC₅₀ value of susceptible strain of *L. orbonalis* to thiacloprid 21.7% SC was 0.00461 ml per *l*.

Table 10. Thiacloprid 21.7% SC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

Sr. No.	Strain	LC ₅₀ ml/g/l	Fiducial limits at 50 %		LC ₉₀ ml/g/l	Slope ± S.E.	x ²	RR
			LL	UL				
1	Ahmednagar	0.01175	0.00395	0.01957	0.35334	0.867 ± 0.258	0.1786	2.55
2	Kolhapur	0.01245	0.00399	0.02099	0.44651	0.824 ± 0.256	0.5401	2.70
3	Nashik	0.01343	0.00483	0.02214	0.43698	0.847 ± 0.256	0.1363	2.91
4	Pune	0.00825	0.00160	0.01533	0.33382	0.798 ± 0.260	0.0465	1.79
5	Sangli	0.01007	0.00122	0.01964	0.88881	0.659 ± 0.252	0.0297	2.18
6	Satara	0.01325	0.00269	0.02428	1.03520	0.677 ± 0.250	0.2141	2.87
7	Solapur	0.01514	0.00620	0.02433	0.44916	0.870 ± 0.255	0.1152	3.28
8	Osmanabad	0.00902	0.00099	0.01787	0.73843	0.670 ± 0.254	0.1428	1.96
9	Susceptible	0.00461	0.00023	0.01064	0.27872	0.719 ± 0.267	0.3458	-

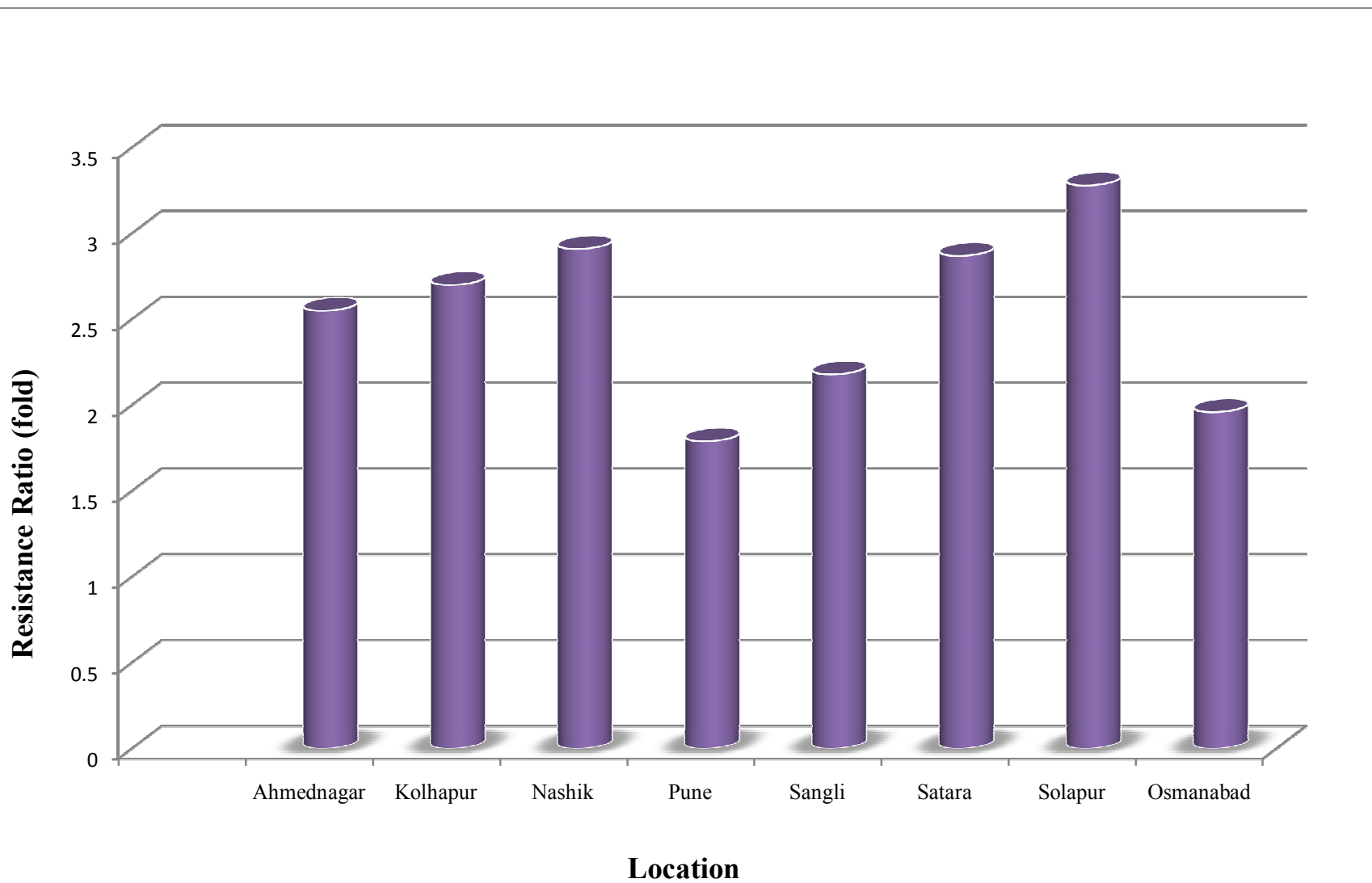
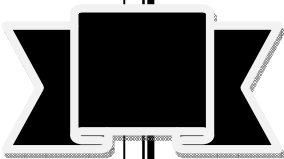


Fig. 10. Thiachloprid 21.7% SC resistance in field population of *Leucinodes orbonalis* (Guenee) infesting brinjal

L. orbonalis population of Solapur noticed highest resistance ratio to thiacloprid 21.7% SC (3.28-fold) followed by Nashik (2.91-fold), Satara (2.87-fold), Kolhapur (2.70-fold), Ahmednagar (2.55-fold), Sangli (2.18-fold), Osmanabad (1.96-fold) and Pune (1.79-fold). The variations of resistance (1.83-fold between Solapur and Pune populations) existed among the field populations assayed. The result showed that 1 of 8 field populations (12.5 per cent) of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Solapur showed decreased susceptibility to thiacloprid 21.7% SC. However remaining 7 of 8 field populations (87.5 per cent) of *L. orbonalis* collected from Nashik, Satara, Kolhapur, Ahmednagar, Sangli, Osmanabad and Pune exhibited susceptibility to thiacloprid 21.7% SC.

The results of present investigation are in accordance with the findings of Kate (2018) who exhibited that all the populations of *L. orbonalis* indicated susceptibility to thiacloprid 21.7% SC with varied level of resistance (1.56-fold to 1.83-fold). Sharma *et al.* (2018) reported that thiacloprid was persistent against *L. orbonalis* ((PT values= 379.17 and 379.16) and LT_{50} values were 3.83 and 3.77 days in 2015 and 2016, respectively. Saimandir and Gopal (2012) proved that thiacloprid at the experimented doses (30 and 60 g·ai per ha) was found ineffective to manage *L. orbonalis* population and was unsafe for human consumption after a waiting period of 3 days.

SUMMARY AND CONCLUSION



Chapter V

SUMMARY AND CONCLUSION

Investigations were carried out to monitor the levels of insecticide resistance in the field populations of *Leucinodes orbonalis* (Guenee) infesting brinjal collected from different locations of Western Maharashtra at the Post Graduate Laboratory, Department of Agricultural Entomology, College of Agriculture, Latur (Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra) during 2018-19. The levels of resistance in the field populations of *L. orbonalis* against commonly used insecticides viz., chlorantraniliprole 18.5% SC, chlorpyrifos 20% EC, cyantraniliprole 10.26% OD, cypermethrin 25% EC, dimethoate 30% EC, emamectin benzoate 5% SG, fenpropathrin 30% EC, lambda-cyhalothrin 5% SC and thiacloprid 21.7% SC were assayed by fruit dip method. The LC₅₀ values obtained for the field populations were compared with the LC₅₀ values of corresponding susceptible strains developed under the protected conditions without selection pressure of any insecticide. The resistance ratios were worked out for comparing the levels of resistance. The results obtained during the course of investigation are as summarized below.

The resistance ratio of chlorantraniliprole 18.5% SC was found to be highest in *L. orbonalis* population of Pune (3.34-fold) followed by Nashik (3.21-fold), Kolhapur (3.19-fold), Solapur (2.94 - fold), Sangli (2.89-fold), Ahmednagar (2.68-fold), Satara (2.25-fold) and Osmanabad (1.91-fold). There was 1.75-fold difference in LC₅₀ values of Pune and Osmanabad strains among the field populations. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Pune, Nashik and Kolhapur showed

decreased susceptibility to chlorantraniliprole 18.5% SC. However, field populations of *L. orbonalis* collected from Solapur, Sangli, Ahmednagar, Satara and Osmanabad exhibited susceptibility to chlorantraniliprole 18.5% SC.

L. orbonalis population of Solapur evidenced maximum resistance ratio to chlorpyrifos 20% EC (4.90-fold) followed by Satara (4.88-fold), Nashik (4.35-fold), Pune (4.15-fold), Sangli (3.83-fold), Kolhapur (3.70-fold), Ahmednagar (3.64-fold) and Osmanabad (3.61-fold). There was 1.36-fold difference in LC₅₀ values of Solapur and Osmanabad strains among the field populations. The result showed that 8 of 8 field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Solapur, Satara, Nashik, Pune, Sangli, Kolhapur, Ahmednagar and Osmanabad evidenced decreased susceptibility to chlorpyrifos 20% EC.

The highest resistance ratio was exhibited to cyantraniliprole 10.26% OD in *L. orbonalis* population of Kolhapur (2.71-fold) followed by Nashik (2.58-fold), Satara (2.31-fold), Sangli (2.27-fold), Pune (2.25-fold), Ahmednagar (1.90-fold), Osmanabad (1.86-fold) and Solapur (1.31-fold). The variations of resistance (2.07-fold between Kolhapur and Solapur populations) observed among the field populations assayed. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Kolhapur, Nashik, Satara, Sangli, Pune, Ahmednagar, Osmanabad and Solapur expressed susceptibility to cyantraniliprole 10.26% OD.

The resistance ratio of cypermethrin 25% EC was found to be maximum in *L. orbonalis* population of Kolhapur (4.98-fold) followed by Pune (4.71-fold), Satara (4.25-fold), Solapur (4.21-fold), Nashik (4.02-fold), Sangli (3.76-fold), Osmanabad (3.33-fold) and Ahmednagar (3.19-fold). There was 1.56-fold difference in LC₅₀ values of Kolhapur and Ahmednagar strains among the field populations. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Kolhapur, Pune, Satara, Solapur, Nashik, Sangli, Osmanabad and Ahmednagar evidenced decreased susceptibility to cypermethrin 25% EC.

The highest resistance ratio of dimethoate 30% EC was noticed in *L. orbonalis* population of Nashik (6.10-fold) followed by Satara (5.44-fold), Solapur (5.34-fold), Kolhapur (5.00-fold), Osmanabad (4.84-fold), Ahmednagar (4.35-fold), Pune (4.31-fold) and Sangli (4.19-fold). There was 1.45-fold difference in LC₅₀ values of Nashik and Sangli strains among the field populations. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Nashik, Satara and Solapur showed low level of resistance to dimethoate 30% EC. However, field populations of *L. orbonalis* collected from Kolhapur, Omanabad, Ahmednagar, Pune and Sangli exhibited decreased susceptibility to dimethoate 30% EC.

L. orbonalis population of Solapur evidenced maximum resistance ratio to emamectin benzoate 5% SG (2.43-fold) followed by Nashik (2.24-fold), Kolhapur (2.14-fold), Satara (2.10-fold), Sangli (2.05-fold), Ahmednagar (1.52-fold), Pune (1.48-fold) and Osmanabad (1.43-fold). The variations of resistance (1.70-fold between Solapur and Osmanabad populations) existed among the field populations assayed. The result showed that field populations of *L. orbonalis* infesting brinjal

collected from Western Maharashtra region i.e. Solapur, Nashik, Kolhapur, Satara, Sangli, Ahmednagar, Pune and Osmanabad evidenced susceptibility to emamectin benzoate 5% SG.

The highest resistance ratio to fenpropathrin 30% EC was registered in *L. orbonalis* population of Ahmednagar (3.90-fold) followed by Solapur (3.68-fold), Pune (3.56-fold), Sangli (3.53-fold), Satara (3.27-fold), Nashik (3.10-fold), Osmanabad (2.74-fold) and Kolhapur (2.64-fold). The variations of resistance (1.48-fold between Ahmednagar and Kolhapur populations) existed among the field populations assayed. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Ahmednagar, Solapur, Pune, Sangli, Satara and Nashik showed decreased susceptibility to fenpropathrin 30% EC. However, field populations of *L. orbonalis* collected from Osmanabad and Kolhapur exhibited susceptibility to fenpropathrin 30% EC.

L. orbonalis population of Nashik noticed highest resistance ratio to lambda-cyhalothrin 5% SC (5.18-fold) followed by Solapur (4.91-fold), Sangli (4.27-fold), Pune (4.09-fold), Kolhapur (4.00-fold), Osmanabad (3.73-fold), Ahmednagar (3.64-fold) and Satara (3.36- fold). The variations of resistance (1.54-fold between Nashik and Satara populations) existed among the field populations assayed. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Nashik showed low level of resistance to lambda-cyhalothrin 5% SC. However, field populations of *L. orbonalis* collected from Solapur, Sangli, Pune, Kolhapur, Osmanabad, Ahmednagar and Satara exhibited decreased susceptibility to lambda-cyhalothrin 5% SC.

The resistance ratio of thiacloprid 21.7% SC was found to be maximum in *L. orbonalis* population of Solapur (3.28-fold) followed by Nashik (2.91-fold), Satara (2.87-fold), Kolhapur (2.70-fold), Ahmednagar (2.55-fold), Sangli (2.18-fold), Osmanabad (1.96-fold) and Pune (1.79-fold). The variations of resistance (1.83-fold between Solapur and Pune populations) existed among the field populations assayed. The result showed that field populations of *L. orbonalis* infesting brinjal collected from Western Maharashtra region i.e. Solapur showed decreased susceptibility to thiacloprid 21.7% SC. However, field populations of *L. orbonalis* collected from Nashik, Satara, Kolhapur, Ahmednagar, Sangli, Osmanabad and Pune exhibited susceptibility to thiacloprid 21.7% SC.

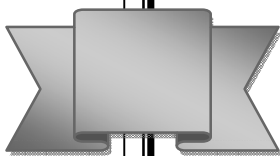
From the results of the present investigation following conclusions can be drawn.

Based on variations in LC_{50} values and comparison with recommended dosages, the insecticidal resistance in *L. orbonalis* infesting brinjal from different locations of Western Maharashtra region was quite alarming to commonly used insecticides viz., chlorantraniliprole 18.5% SC, chlorpyrifos 20% EC, cyantraniliprole 10.26% OD, cypermethrin 25% EC, dimethoate 30% EC, emamectin benzoate 5% SG, fenpropathrin 30% EC, lambda-cyhalothrin 5% SC and thiacloprid 21.7% SC. Among the insecticides tested, chlorpyrifos 20% EC, cypermethrin 25% EC, dimethoate 30% EC and lambda-cyhalothrin 5% SC were observed to be less toxic to all the field populations of *L. orbonalis* infesting brinjal, evidenced decreased susceptibility to low resistance levels. However among the insecticides tested, chlorantraniliprole 18.5% SC, cyantraniliprole 10.26% OD, emamectin benzoate 5% SG, fenpropathrin 30% EC and thiacloprid 21.7% SC were found to be highly toxic to all the field populations of *L.*

orbonalis infesting brinjal, evidenced susceptibility to decreased sensitivity.

Thus, chlorpyrifos 20% EC, cypermethrin 25% EC, dimethoate 30% EC and lambda-cyhalothrin 5% SC evidenced increasing trends towards resistance hence, it is suggested that these insecticides should be used wisely. It is also suggested that cyantraniliprole 10.26% OD, chlorantraniliprole 18.5% SC, emamectin benzoate 5% SG, fenpropathrin 30% EC and thiacloprid 21.7% SC can be used in rotation with the other insecticides for management of *L. orbonalis* and delay the development of insecticide resistance,

The present study proved that insecticide resistance is widespread in the majority of the areas surveyed. Unless a strong resistance management plan is implemented, the problem is likely to become even more severe. Apart from regulation and restriction on the use of insecticides, it may be useful to consider exploring other options such as the use of newer molecules that are effective against resistant insects or alternative methods of pest control such as bio-pesticides and biocontrol agents. Such approaches can reduce the selection pressure of insecticides on *L. orbonalis* infesting brinjal and may be help in delaying the further development of resistance.



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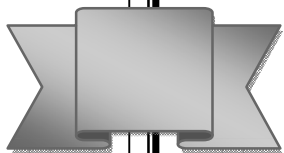
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ABSTRACT

DISSERTATION ABSTRACT

Title : MONITORING OF INSECTICIDAL RESISTANCE IN *Leucinodes orbonalis* (GUENEE) INFESTING BRINJAL

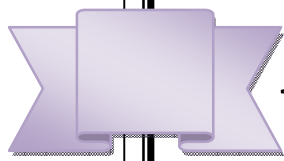
Name of student : Desai Ranjit Uttamrao

Reg. no. : 2017A/61ML

Name of research guide : Dr. V.K. Bhamare

The studies on “Monitoring of insecticidal resistance in *Leucinodes orbonalis* (Guenee) infesting brinjal” were conducted at the Post Graduate Laboratory, Department of Agricultural Entomology, College of Agriculture, Latur (Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra) during 2018-19. The development of resistance to insecticides was investigated by collecting field populations of *L. orbonalis* infesting brinjal from different locations of Western Maharashtra, India (Ahmednagar, Kolhapur, Nashik, Pune, Sangli, Satara, Solapur and Osmanabad). Based on variations in LC₅₀ values and comparison with recommended dosages, *L. orbonalis* infesting brinjal collected from different locations of Western Maharashtra indicated change in susceptibility to commonly used insecticides *viz.*, chlorantraniliprole 18.5% SC, chlorpyrifos 20% EC, cyantraniliprole 10.26% OD, cypermethrin 25% EC, dimethoate 30% EC, emamectin benzoate 5% SG, fenprothrin 30% EC, lambda-cyhalothrin 5% SC and thiacloprid 21.7% SC. *L. orbonalis* population infesting brinjal collected from Nashik recorded 6.10-fold resistance to dimethoate 30% EC which was highest compared to other field populations. The resistance ratios

varied greatly among the populations of *L. orbonalis* viz., dimethoate 30% EC (4.19- to 6.10-fold), lambda-cyhalothrin 5% SC (3.36- to 5.18-fold), cypermethrin 25% EC (3.19- to 4.98-fold), thiacloprid 21.7% SC (1.79- to 3.28-fold), chlorantraniliprole 18.5% SC (1.91- to 3.34-fold), cyantraniliprole 10.26% OD (1.31- to 2.71-fold), chlorpyrifos 20% EC (3.61- to 4.90-fold), fenpropathrin 30% EC (2.64- to 3.90-fold) and emamectin benzoate 5% SG (1.43- to 2.43-fold). The resistance ratio of insecticides viz., chlorantraniliprole 18.5% SC, cyantraniliprole 10.26% OD, emamectin benzoate 5% SG, fenpropathrin 30% EC and thiacloprid 21.7% SC among all field populations of *L. orbonalis* infesting brinjal exhibited susceptibility to decreased sensitivity to these insecticides while, the resistance ratio of chlorpyrifos 20% EC, cypermethrin 25% EC, dimethoate 30% EC and lambda-cyhalothrin 5% SC indicated decreased susceptibility to development of low level of resistance. Thus, chlorpyrifos 20% EC, cypermethrin 25% EC, dimethoate 30% EC and lambda-cyhalothrin 5% SC showed increasing trends towards resistance hence, these insecticides should be used wisely. However chlorantraniliprole 18.5% SC, cyantraniliprole 10.26% OD, emamectin benzoate 5% SG, fenpropathrin 30% EC and thiacloprid 21.7% SC can be used in rotation with the other insecticides to suppress the resistant population of *L. orbonalis* in brinjal ecosystem.



APPENDIX

APPENDIX I

Week wise meteorological data during the period of investigation

Year : 2018 Latitude : 18°24'N
 State : Maharashtra Longitude : 77°E 36'
 District : Latur Altitude : 633.85 m.
 Zone : Deccan plateau Soil type : Vertisol

S. M. W.	Date	Total rainfall (mm)	Rainy days (No.)	Temperature °C		Relative Humidity (%)	
				Max.	Min.	AM	PM
23	04-10 June	122	4	32.2	22.7	92	61
24	11-17 June	36	2	34.1	24.5	82	44
25	18-24 June	21.0	4	32.3	23.2	90	62
26	25-01 July	77	1	32.5	23.2	90	53
27	02-08 July	0.0	-	30.3	23.6	86	64
28	09-15 July	31	3	28.8	22.6	89	64
29	16-22 July	17	1	28.3	23.9	86	74
30	23-29 July	-	-	28.2	24.1	83	68
31	30-05 Aug	-	-	29.4	23.1	79	60
32	06-12 Aug	-	-	30.1	22.5	75	61
33	13-19 Aug	76.8	3	28.2	20.9	91	78
34	20-26 Aug	49.6	4	27.2	21.1	92	83
35	27-02 Sept	24	1	29.1	21.4	84	68
36	03-09 Sept	0.0	--	28.6	19.8	78	64
37	10-16 Sept	0.0	--	30.3	19.1	71	60
38	17-23 Sept	0.0	--	30.9	18.8	70	60
39	24-30 Sept	0.0	--	32.9	18.6	65	52
40	01-07 Oct.	6.6	1	33.3	18.8	58	45
41	08-14 Oct	0.0	--	33.1	18.9	58	30
42	15-21 Oct	0.0	--	32.8	18.7	61	32
43	22-28 Oct	0.0	--	32.4	18.6	61	31
44	29-04 Nov.	0.0	--	30.4	18.9	51	37
45	05-11 Nov.	0.0	-	31.5	21.2	51	38
46	12-18 Nov.	0.0	-	31.4	14.0	48	30
47	19-25 Nov.	17.2	1	29.1	13.7	45	43
48	26-02 Dec.	0.0	-	28.7	12.8	46	32
49	03-09 Dec.	0.0	-	30.4	14.0	49	35
50	10-16 Dec.	0.0	-	28.1	11.8	64	38
51	17-23 Dec.	0.0	-	27.7	11.6	49	36
52	24-31 Dec.	0.0	-	26.3	10.1	46	30