DEVELOPMENT OF RESISTANCE TO SOME INSECTICIDES IN DIAMONDBACK MOTH, *Plutella xylostella* (L.)

THESIS

By

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Submitted to

CSK HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA
PALAMPUR 176 062 (HP) INDIA

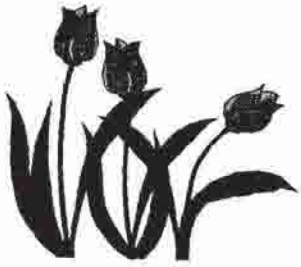
IN

Partial fulfilment of the requirements for the degree

OF

DOCTOR OF PHILOSOPHY IN AGRICULTURE
(ENTOMOLOGY)
(2003)

Dedicated
To
My
Reverend
Parents



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CERTIFICATE – I

This is to certify that the thesis entitled "**Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)**" submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Entomology** of Choudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Ramesh Lal** (Admission No. A-98-40-04) son of **Shri Dassu Ram** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Bajaura

Dated: the 16th June, 2003

(Jitender Kumar Sharma)
Chairman
Advisory Committee

CERTIFICATE – II

This is to certify that the thesis entitled "**Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)**" submitted by **Mr. Ramesh Lal** son of **Shri Dassu Ram** to the Choudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Entomology** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Acknowledgements

Words are not at my command to express my gratitude and what is in my heart to the Merciful and Compassionate God with whose blessings I have able to complete this work.

I feel a great contentment to express my heartiest and heartful gratitude to my dignified Chairman Dr. Jitender Kumar Sharma, Sr. Entomologist, CSKHPKV, HAR & EC, Bajaura Kullu (HP) for his benevolent and everlasting guidance, sustained encouragement, keen interest and constructive rendered during the entire course, which led to the successful completion of the present work.

I emphatically express my loyal and venerable thanks to Dr. D.C. Sharma, Scientist (Entomology), Dr. Surjeet Kumar, Asstt. Scientist (Entomology), Dr. Y.S. Paul, Professor (Plant Pathology), Dr. D.K. Sharma, Scientist (Tea Husbandary and Technology), and Dr. R.P. Kaushal, Professor (Plant Pant Pathology). This piece of investigation owes its completion to their valuable suggestions and constructive criticism, as members of my Advisory committee.

I am deeply indebted to Dr. P.C. Sharma, Dr. A. K. Sood, Dr. (Mrs.) Nirmala Devi, Dr. P. K. Mehta, Dr. Y.S. Chandel, Dr. R.S. Chandel, Dr. Kuldeep Kumar Verma, Dr. D.N. Vaidya, Dr. R.M. Bhagat, Dr. N.P. Kashyap and Dr. S.S. Thakur for their valuable help, judicious guidance and encouragement provided during the entire course of these studies.

I am highly thankful to Dr. Desh Raj Professor & Head, Department of Entomology for generously providing me the facilities required during the course of these investigations.

I also want to place on records my sincerest thanks to Dr. Vinod Sharma, Sh. P.C. Dhadwal, Dr. S.K. Guleria, Dr. Sukh Dev, Dr. D.K. Parmar, Dr. K.C. Sharma, Dr. R.C. Chauhan, Dr. B.K. Sharma, Dr. Shyam Verma, Dr. D.R. Thakur, Dr. V.K. Rathee, Dr. R.S. Jamwal and Dr. Virender, CSK HPKV, HAR & EC, Bajaura, Kullu, for their kind co-operation and help.

Words of special thanks are due Dr. R.N. Barwal (IARI, Regional Station Katrain) Dr. J.R. Thakur (Associate Director) and Dr. J.P. Sharma, UHF, RRS, Bajaura (Kullu).

I am heartily thankful to Dean, Post Graduate Studies, Dr. V. K. Gupta for constant encouragement and providing me financial assistance during my studies.

The co-operation and assistance extended by faculty members, office, laboratory and library staff (specially Mr. Arvind and Mr. Dev Walia) & field workers of Palampur and Bajaura is thankful acknowledged.

I also feel indebted to all my friends, Parmod Verma, Anil Chaudhary, Rajesh Dogra, Gagnesh, Viveka, Dorin, Rakesh Bandral (Raja ji), Vinod Sharma ji, Gopal Katna ji, Aditya, Indra, Poonam, Ankur, Sanjeev Pathak, Yadvinder, Nitin, Girish Gautam, Amit Chaudhary, Anjana, Sanjeev and Vinod for their timely help and charming company.

I seize this opportunity to express my deep gratitude to Sh. Dhani Ram my maternal uncle always encouraged me to take up these studies.

Ever effort motivated by an ambition has an inspiration behind. I owe this pride place to my affectionate parents, who encouraged me to undergo higher studies. Their selfless persuasions and sacrifice, heartfelt blessings, everlasting love and firm faith have made this manuscript a remuneration to translate their dreamism to reality.

With personal touch of emotions, I express my heartiest thanks to my brother Sh. Roshan Lal, Bhabhi ji (Smt. Sheela Devi), sisters, Hema Devi and Satya Bhama, nephew Dinesh and niece Surbhi for their affection, constant encouragement and good wishes added as a premium to my achievements.

Special thanks are also due to Dr. B.S. Deor, Assoc. Director, Dr. D.S. Thakur (Ex. Assoc. Director) and my major Advisor Dr. Jitender Kumar, HAREC, Bajaura for providing me necessary facilities to make this manuscript in present form.

Acknowledgements are inherently endless and incomplete, and I wish indulgence from the many friendly and helpful people whom I do not name here.

Needless to say, errors and omissions are mine.

Palampur (HP)
Dated: 16th June, 2003

(Ramesh Lal)

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Chapter - I

INTRODUCTION

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae) is a cosmopolitan species and was reported for the first time from India by Fletcher (1914). It is now an established pest of cruciferous crops particularly of cauliflower and cabbage, and has become a limiting factor in the cultivation of these crops through out the country (Verma *et al.*, 1972; Chand and Choudhary, 1977; Bhalla and Dubey, 1986; Chelliah and Srinivasan, 1986; Chauhan *et al.*, 1994; Kandoria *et al.*, 1994; Devi and Raj, 1995; Raju and Singh, 1995; Renuka and Regupathy, 1996; Sood *et al.*, 1996 and Kumar *et al.*, 2000). Introduction of early and late maturing varieties for intensive cultivation of cauliflower and cabbage, involving more number of crops in sequence during a year, provide a continuous food supply to diamondback moth, thereby increasing the pest incidence tremendously. In Himachal Pradesh, cauliflower and cabbage are grown over an area of about 1370 ha and 2200 ha, respectively (Anonymous, 2003). In mid- and high- hill areas of the state these crops are grown as off-season and provide rich dividends to the farmers. To get blemish free heads of these crops, vegetable growers generally resort to frequent and indiscriminate use of insecticides.

One of the important consequences of indiscriminate use of insecticides is the development of resistance in the target species. With the steady proliferation of new insecticides and their use in insect control programmes, the number of resistant insect species of agricultural importance has increased quickly. The number of confirmed resistant insects

and mite species, all over the world continued to rise to a level of more than 500 (David, 1993). The concentrated effect of the exponentially increasing cost of insecticide development, the dwindling rate of commercialization of new materials and the demonstration of cross-and multiple- resistance to new classes of insecticides before they are fully commercialized, make insect-pest resistance the greatest single problem facing applied Entomology (Metcalf, 1980). Due to frequent and indiscriminate use of insecticides, the diamondback moth has developed resistance to several groups of insecticides in all over the world and the problem is very serious in South East Asian countries (Noppun *et al.*, 1984; Cheng, 1988; Sexena *et al.*, 1989; Talekar and Shelton, 1993; Joia *et al.*, 1997 and Joia and Udeaan, 1998). In India, resistance in this pest has been reported from Punjab and Haryana against several organochlorine and organophosphate insecticides viz., BHC, ethyl parathion, fenitrothion and malathion (Verma and Sandhu, 1967; Verma *et al.*, 1972; Deshmukh and Saramma, 1973; Chawla and Kalra, 1976; Chawla and Joia, 1991 and Sannaveerappanava and Viraktamath, 1997). High degree of resistance to synthetic pyrethroids (cypermethrin, fenvalerate and deltamethrin) and quinalphos has been reported in field populations of *P. xylostella* collected from cabbage and cauliflower crops in various regions of the country, namely Panipat in Haryana, Jalandhar, Phagwara, Mansa, Patiala and Samrala in Punjab, Ranchi in Bihar, Jaunpur in Utter Pradesh, Bangalore in Karnataka, Delhi and Tamil Nadu (Saxena *et al.*, 1989; Renuka and Regupathy, 1996; Joia and Udeaan, 1998). Raju and Singh (1995) found the populations of this pest collected from cauliflower at two localities in Varanasi disrtict of Uttar Pradesh to be highly resistant to cypermethrin and fenvalerate and to a lesser extent to endosulfan and quinalphos.

In Himachal Pradesh, malathion, endosulfan, deltamethrin, cypermethrin and fenvalerate are in recommendation for the control of diamondback moth (Anonymous, 2002) and vegetable growers generally resort to frequent and indiscriminate use of these insecticides. As resistance is the result of Darwinian selection, it should be expected to develop whenever insects are exposed for long periods to selective levels of insecticides that cause some degree of mortality short of 100 per cent. However, such possibility has not been explored for diamondback moth in Himachal Pradesh. In view of above, present study was carried out with the following objectives:

i) To determine the status of resistance to malathion, endosulfan and fenvalerate in diamondback moth, *P. xylostella* (L.) collected from various vegetable growing localities of different districts of Himachal Pradesh.

ii) To study the development of resistance to malathion, endosulfan and fenvalerate in *P. xylostella* for determining that after how many generations of continuous exposures to these insecticides the pest would develop resistance to them.

iii) To study the cross- resistance spectrum of resistant strains for finding the alternative potent insecticides against them and

iv) To study the biological characteristics of resistant strains for their relative competitive ability in comparison to the susceptible strain.

REVIEW OF LITERATURE

Chapter –II

REVIEW OF LTERATURE

Diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae) is a small insect, has developed resistance to almost all the groups of insecticides employed for its control and threatened the cultivation of crucifers all over the world. Consequently, it has attained the status of an international pest (Talekar and Shelton, 1993; Verkerk, and Wright, 1996).

The literature pertaining to present dissertation has been reviewed under the following heads:

2.1. Status of resistance to insecticides

2.2 Development of resistance to insecticides

2.2.1 Diamondback moth, *Plutella xylostella* (L.)

2.2.2 Resistance to malathion, endosulfan and fenvalerate in other agricultural insect-pests.

2.3 Cross-resistance spectrum of resistant-strains

2.3.1 Diamondback moth, *Plutella xylostella* (L.)

2.3.2 Malathion, endosulfan and fenvalerate resistant strains of other agricultural insect-pests

2.4 Biological characteristics of resistant strains

2.1 Status of resistance to insecticides

First scientifically documented report that insects developed resistance to insecticides was that of Melander (1914) of the Sanjose Scale, *Quadraspidiotus perniciosus* (Comstock). The number of arthropods developing resistance to insecticides rose steadily in the pre-DDT era (11 species). In the post-DDT era, there has been a virtual onslaught of resistance. The number of arthropod species recorded resistant to various pesticides was 137 in 1960 (Brown, 1961), which rose steadily to 447 in 1984. In all over the world, more than 500 species of insects and mites are estimated to have developed resistance (David, 1993). Over half of these resistant pests are reported to be agriculturally important and 3 per cent are beneficial predators, parasites and pollinators. Most of these species exhibit resistance to more than one group of chemicals (Davies, 1992).

In Asian countries, the first report of development of resistance to insecticides was from India where Singhara beetle, *Galerucella birmanica* (Jacoby) was found resistant to DDT and HCH (Pradhan *et al.*, 1963). Since then 14 other pests have been demonstrated to become resistant to different insecticides in one or more countries. Pyrethroid resistance in cotton bollworm, *Helicoverpa armigera* (Hubner) was first recorded in eastern Andhra Pradesh in 1987 (Dhingra *et al.*, 1988). Monitoring of *H. armigera* populations at six widely spaced locations in India during 1993-94 revealed that insecticide resistance is now ubiquitous in this pest. High level of resistance to cypermethrin, fenvalerate and endosulfan was recorded in all the regions while in case of quinalphos, only low to moderate level of resistance was observed (Dhaliwal and Arora, 1998)

In India, the status of insecticide resistance in insect-pests of Agriculture and public health importance has been reviewed by Saxena (1985), Bhatia (1986), and Mehrotra (1991,

1995). Resistance in the field has been encountered in ten major pest species viz., *Galerucella birmanica* Jacoby, *Spodoptera litura* (Fab.), *Plutella xylostella* (Linn.), *Helicoverpa armigera* (Hub.), *Pectinophora gossypiella* (Linn.), *Mylabris pustulata* Thunb., *Lipaphis erysimi* (Kalt.), *Myzus persicae* (Sulz.), *Aphis craccivora* Koch and *Empoasca kerri* Pruthi (Mehrotra, 1995).

2.2 Development of resistance to insecticides

2.2.1 Diamondback moth, *Plutella xylostella* (L.)

The status of insecticide resistance in diamondback moth, *Plutella xylostella* (L.) seems quit serious in various parts of the world. It has been found to develop resistance to insecticides belonging to organochlorines, organophosphates, carbamates, synthetic pyrethroides and insect growth regulators. High level of resistance in field populations of this pest has been reported to malathion from Malaysia (Anonymous, 1973), Taiwan (Liu *et al.*, 1982) and China (Tang and Zhou, 1992), and to endosulfan from Taiwan (Lee and Lee, 1979) and North Florida (Yu and Nguyen, 1992).

The pest was found to develop resistance to almost all chlorinated hydrocarbon insecticides in field use in Venezuela (Cermeli, *et al.*, 1969). Chawla and Kalra (1976) reported that *P. xylostella* collected from three locations viz, Ludhiana, Jullunder and Amritsar of Punjab showed reduced susceptibility to malathion (LC_{50} <0.5%). Populations from Ludhiana and Amritsar were also tolerant to fenitrothion, lindane, methyl parathion and dichlorvos. The populations were also 8 times resistant to endrin. It was concluded that there were multiple insecticide resistant strains of *P. xylostella* in Punjab. Sudderuddin and Kok (1978) recorded five-fold resistance in diamondback moth (LD_{50} basis) to fenvalerate only two years after its use in Malaysia.

Sudderuddin and Kok (1978) evaluated 10 insecticides against 4th instar larvae of diamondback moth for resistance in a farm in Malaysia. LD_{50} values showed that the strain was 2096, 626, 530, 64, 40, 16, 12, 6, 6 and 5 times resistant to malathion, chlorpyrifos-methyl, DDT, gamma-BHC, dichlorvos, cartap, methomyl, methamidophos, carbaryl and resmethrin, respectively. Lee and Lee (1979) carried out studies on the status of insecticide resistance to *P. xylostella* in Tawain. The resistance spectrum of strains collected from various vegetable crops in the field was determined by the topical application of several insecticides. Most of the strains showed high levels of resistance to endosulfan. Barroga *et al.* (1981) tested larvae of *P. xylostella* collected from Laguna and Manila (Trinidad) and found 305- and 735-fold resistance to malathion. Population of *P. xylostella* collected in Taiwan from December 1980 to April 1981 were found 32.5, 10.9, 3.6, 48.5 and 75.0 times resistant to carbofuran, mevinphos, cartap, permethrin and fenvalerate, respectively (Cheng, 1981). Liu *et al.* (1981) reported that the field collected populations in Taiwan developed high resistance to permethrin (77.6x), cypermethrin (316.4x), deltamethrin (714.3x) and fenvalerate (701.5x) and to a lesser extent to diazinon (15.1x). Heong *et al.* (1982) found 700-fold resistance to permethrin in a population collected from Cameron Highlands in Malaysia. Diamondback moth populations collected from various parts of Punjab were also found to develop resistance to diazinon (Anonymous, 1986). Wu and Gu (1986) reported that multiple applications of fenvalerate to control *P. xylostella* resulted in a quick establishment of resistance in Shanghai, China. Field collected strain of *P. xylostella* was found to develop high levels of resistance to phenthoate in the laboratory after 8 selections during 9 generations. This strain exhibited 172- and 287- fold resistance to phenthoate at LD_{50} and LD_{95} values, respectively (Noppun *et al.*, 1986). Hama

(1987) also reported high level of resistance to fenvalerate and organophosphorus or carbamate insecticides in Japan.

Noppun *et al.* (1987) found that after 8-9 generations of continuous selection pressure there is a rapid development of resistance to fenvalerate with in a short period of time. The development of resistance was slow in earlier stages, faster in the middle and rapid in the later stage. Selection of the susceptible strain with malathion over 8 generations gave rise to an increased resistance to malathion (Doichuanngam and Thornhill, 1989). Kao *et al.* (1989) in a susceptible strain of *P. xylostella* found > 2600 fold resistance to methyl parathion. Population collected from cabbage fields in Japan and assessed by a leaf-dipping method were found highly resistant to organo-phosphates (Kimura, 1989). Noppun *et al.* (1989) in laboratory studies found >500 fold resistance to racemic fenvalerate to the population collected in Japan than susceptible strains which had previously been collected from the fields in Kagoshima and Okinawa. Resistance to acephate, trizophos and decamethrin (deltamethrin) was found to be 172-, 31- and 267- folds, respectively as compared to permethrin in Lembang (Indonesia) (Sastrosis Wojo *et al.*, 1989).

Ovalle and Cave (1989) found 45.29, 20.75 and 14.37 times resistance to methomyl in a population collected from El Zamarano, Tatumbla and San Juan del Rancho in Honduras, respectively. Saxena *et al.* (1989) reported high degree of resistance to cypermethrin (x40.69 to 144.90), fenvalerate (x43.37 to 178.80) and deltamethrin (x96.00 to 191.76) in diamondback moth populations collected from Ranchi in Bhiar, Jaunpur in Utter Pradesh, Panipat in Haryana, Bangalore in Karnataka and Delhi. Hama (1990) reported the resistance against organophosphates in more than 30 populations of diamond back collected from various localities in Japan. He found higher resistance ratio for thiono-type than for phosphate

and dithio-type insecticides. He also reported high resistance to pyrethroids in various places in Southwestern Japan since 1984.

Laboratory studies were carried out with a fenvalerate resistant strain of *P. xylostella* to test development of insecticide resistance. After selection for 24 generations, resistance to fenvalerate was found to be 66.2- fold compared to the parent strain (Kim *et al.*, 1990). Strains from the highly intensive cabbage growing areas West of Bangkok showed the following resistance patterns: resistance factors (RF) > 3000 for DDT, lindane, endrin, parathion-methyl and some other organophosphates, RF > 125 for carbamates, pyrethroids and chitin synthesis inhibitors and RF > 25 for *Bacillus thuringiensis* and methamidophos (Zoebelein, 1990). Diamondback moth resistance to *Bacillus thuringiensis* Berliner was also reported from Hawaii by (Tabashnik *et al.*, 1990). Chawla and Joia (1991) reported that the populations of *P. xylostella* collected from various parts of Punjab showed an increase in LC_{50} values by 22 times in fenvalerate for Jalandhar, 10 times in cypermethrin for Ludhiana populations by 1988-89 when compared with their corresponding base line LC_{50} values obtained during 1984-85. Ferre *et al.* (1991) found >200-fold resistance to *Bacillus thuringiensis* crystal protein in field population as a susceptible laboratory strain. Song (1991) found resistance to *Bacillus thuringiensis* in Korean strains. Tanaka and Kimura (1991) also reported high resistance (LC_{50} > 280 ppm) to the *Bacillus thuringiensis*. The populations collected from Sanghai, Guangzhou and Jiangxi in China were resistant to DDT, organophosphates, carbamates and pyrethroids. *P. xylostella* collected from Shanghai and Guangzhou had become strongly resistant to all classes of insecticides. Resistance was particularly strong to pyrethroids: >10, 414-fold to deltamethrin, 2103- and > 3569- fold to fenvalerate and 245- and 1533- fold to permethrin (Tang *et al.*, 1992). Yu and Nguyan (1992) reported that a strain of *P. xylostella*

collected from cabbage in North Florida in 1991 showed high resistance to pyrethroids (ranged from 2132- to 82475- fold) and was highest to fenvalerate. Resistance to organophosphates ranged from 20- to 73- fold and was highest to diazinon. Resistance to carbamates, methomyl and carbofuran was 409- and 405- fold, respectively. Resistance to the endosulfan was 25-fold. Field populations of the pest collected from Kwangju, Kimbal, Jeju and Inje areas of Korean Republic showed 7.5 to 141.7 times higher resistance to cypermethrin, 10.5 to 33.3- fold resistance with cartap hydrochloride and from 1.9 to 8.1 times higher resistance to *B. thuringiensis* than susceptible strain (Lee *et al.*, 1993). Wang *et al.* (1993) found that susceptible plutellids collected from Shenzhen showed 15- fold resistance in 1991 and 71- fold resistance to chlorfluazuron in 1992 compared with a sensitive strain.

Zhou *et al.* (1993) reported that the Shanghai strain had developed resistance to deltamethrin (more than 10414- fold), to permethrin (245- fold) and to fenvalerate (2102-fold) while the Gwmgzhou strain possessed more than 10414- fold, 1533- and more than 3569- fold resistance to the above pyrethroids, respectively as compared to the Nanehang strain. Cho and Lee (1994) found that triflumuron and lambda-cyhalothrin strain at 8th selected generation showed 37.4- and 29.1- fold resistant levels, respectively as compared to the susceptible strain. The resistant levels shown by *B. thuringiensis*, prothiophis (prothiophos) and cartap hydrochloride selected strains at the 8th generation were 24.0-, 14.3- and 9.1- fold, respectively. Resistance to insect growth regulators namely teflubenzuron and chlorfluazuron has also been reported in this insect from Malaysia (Furlong and Wright, 1994). Studies undertaken by Liu *et al.* (1995) on the selection of strain of *P. xylostella* resistant to deltamethrin showed that after 65 generations of selection resistance had increased by 1163-fold. Raju and Singh (1995) found two populations of this pest collected from cauliflower at

two localities in Varanasi district of Uttar Pradesh to be highly resistant to endosulfan and quinalphos. Sun *et al.* (1995) reported resistance of *P. xylostella* to dichlorvos, cyanophos, deltamethrin, fenvalerate, methomyl and thiofanox from 4 areas of South China. Joia *et al.* (1996) reported high resistance to cypermethrin (2800 times), fenvalerate (2700 times) and quinalphos (70 times) in *P. xylostella*. Renuka and Regupathy (1996) reported that resistance frequency was maximum for fenvalerate followed by quinalphos, monocrotophos, cartap hydrochloride and carbofuran in all the three locations namely Coimbatore, Ooty and Oddanchatram in Tamil Nadu.

Resistance ratios of 197.47 and 100.29- fold for fenvalerate and phosmet, respectively were determined from the field in Wuhan (China) in comparison with a susceptible strain (Zhu *et al.*1996). Garriodo *et al.* (1997) found that this pest had developed resistance to deltamethrin and endosulfan in Chile. The resistance factors (RF) for the respective insecticides were 14.47 and 3.07 in comparison to the susceptible strain. Chung *et al.* (1997) reported that *P. xylostella* showed 581-, 18-, 19- and 11- fold resistance to fenvalerate, cypermethrin, furathiocarb and prothiocarb in Chinju strain (Korean Republic), respectively, and 38- and 9- fold resistance to fenvalerate and furathiocarb in a Seosang strain. Kalra *et al.* (1997) found 138.74, 28.47, 6.09 and 5.03- fold resistance to monocrotophos, malathion, endosulfan and dichlorvos, respectively in the population collected from cauliflower fields around Panipat (Haryana). However, Rosa *et al.* (1997) found that in Central Zone of Chile *P. xylosteila* showed only low level of resistance to deltamethrin and no resistance to endosulfan. Cameron and Walker (1998), in Newzealand, observed highlevel of resistance to lambda – cyhalothrin. Joia and Udeaan (1998) reported very high levels of resistance varying from 1110

to 2830, 1600 to 3200 and 40 to 128 for cypermethrin, fenvalerate and quinalphos, respectively in populations collected from Jalandhar, Phagwara, Mansa, Patiala and Samrala.

2.2.2 Resistance to malathion, endosulfan and fenvalerate in other agricultural insect-pests

2.2.2.1 Malathion

Malathion is a commonly used organophosphorus insecticide introduced in 1950 by the American Cynamid Company (Anonymous, 1979). Reports of malathion resistance in insect-pests of crops started appearing in the early sixties from Japan (Hayashi and Hayakawa, 1962). The pest wise account of development of malathion resistance in crop pests is given below:

i) *Laodelphax striatellus* Fallen

Kimura (1965) reported 6.43-fold malathion resistance in strain of *L. striatellus* from Hiroshima Prefecture in comparison to strain from Osaka Prefecture and said that the repeated application of malathion was one of the factors contributing to the development of resistance. Ozaki *et al.* (1973) reported that when nymphs of *L. striatellus* were exposed to malathion, alternately to malathion and carbaryl, 11-fold resistance to malathion but none of the carbaryl was found in nymphs of F_{12} generation. Nagata and Ohira (1986) reported 89-and 272- fold resistance in *L. striatellus* populations from Miyazaki and the East China Sea as compared to a population tested in 1967.

ii) *Sogatella furcifera* Horvath

Seven strains of the white backed plant hopper, *S. furcifera* collected from the fields in Japan during 1985-87 showed high levels of resistance (9.37-fold) to malathion. Malathion

applied as dust at 0.9 kg a.i./ha was ineffective to control this pest (Hosoda, 1989).

iii) *Trialeurodes vaporiorum* (Westw.)

Wardlow *et al.* (1972) tested six populations of the white fly (*T. vaporiorum*) collected from South-east England for resistance to malathion by dipping leaves infested with first instar nymphs in aqueous emulsions at concentrations ranging 2 to 3, 9 to 10 ppm malathion. Mortality was assessed 5-days after treatment. Estimated resistance varied from 6-100 times in comparison to a population highly susceptible to malathion. Elhag and Horn (1984) selected a strain of *T. vaporiorum* with a history of insecticide exposure with malathion sufficient to cause 80-90 per cent mortality. After 13 generations, malathion resistance had increased to 55-fold.

iv) *Myzus persicae* (Sulz.)

Shirck (1960) found that several strains of the aphid showed differential susceptibility to malathion in USA and the maximum tolerance (8.6-fold) was reported in the Maryland strain. Laboratory studies carried out by Hurkova (1970) in Czechoslovakia to determine the incidence of resistance to organophosphorus insecticides in laboratory-bred strains of *M. persicae* deriving from four green house populations, two strains were found to be resistant to malathion. A population of *M. persicae* collected from glasshouse on capsicum in New Zealand also showed resistance to malathion (Baker, 1978).

Susceptibility to recommended insecticides was tested by Udeaan and Narang (1993) to the population of *M. persicae* collected during 1988-90 from different locations in Punjab. The aphid population collected from Dugri in 1988 was the most susceptible to malathion. In comparison to this, populations collected from Rania and Mohorana in 1989 and from

Talwandi in 1990 were 12.6-, 16- and 17.1-times tolerant to malathion.

v) *Lipaphis erysimi* (Kalt.)

A survey of mustard aphid, *L. erysimi* populations at 6 widely separated locations viz; Bhanohar, Kohara, Mangarh, Mundian Kalan, PAU Farms and Rurka, for resistance to insecticides in Punjab indicated that *L. erysimi* at Bhanohar, Mangarh and Mundian Kalan had developed 4 to 6-fold tolerance to malathion (Udeaan and Narang, 1986).

vi) *Aphis gossypii* (Glov.)

A significant level of resistance to malathion was exhibited by a colony of *A. gossypii* collected from cotton following a control failure near Stonville, Mississippi. Resistance was measured after 12 months in culture with no insecticide exposure, indicating that resistance might remain stable in the absence of selection pressure (O'Brien and Graves, 1992).

vii) *Mylabris pustulata* Thunb.

A comparison of LC_{50} values for commonly used and recommended insecticides determined during the last two and a half decades (1968-1991) in India revealed a shift in the level of susceptibility of blister beetle, *M. pustulata* to malathion. There was about 2.57-fold increase in LC_{50} value of malathion (Dhingra and Sarup, 1992).

viii) *Epilachna varivestis* (Muls.)

Palam (1949) found rotenone tolerance in *E. varivestis* in New York first time in 1949, where 1.0 per cent dusts were needed for the control afforded by 0.75 per cent dusts during previous 20 years. In 1952, it was detected in Connecticut where the concentrations of dusts necessary to obtain 90 per cent control was 5 times as great as in 1942 but did not require the changing of the insecticide (Turner, 1953). Control failure began to be observed in 1951 around Mills River, North Corolina. Field tests showed only 70 per cent control herewith

doses that controlled 95 per cent elsewhere. Laboratory tests in 1954 showed the Mills River Strain to be 5 times as resistant as the normal (Brett and Brubaker, 1955).

ix) *Epilachna sparsa* (Hbst.)

Senapati and Satpathy (1980, 1982) studied the development of malathion and carbaryl resistance in *E. sparsa* under laboratory conditions. They found that selection of third instar grubs of the beetle with malathion resulted in 3.01-, 5.10- and 23.32-fold resistance in the 5th, 9th, and 13th generation of selection, respectively when assessment was made by the leaf-dip method. By the direct spray method, the resistance ratio of 13.20 was obtained in F_{13} generation. The carbaryl selected strain exhibited resistance ratios of 2.08, 3.33 and 8.20 to carbaryl in F_5, F_9 and F_{13} generations, respectively when assessed by the leaf dip method. The level of resistance determined by the direct spray method was 4.78-fold to the compound in F_{13} generation.

x) *Epilachna vigintioctopunctata* (Fab.)

Jaganmohan and Prasad (1984) reported the failure of fenvalerate (0.1 kg a.i./ha), endosulfan (0.7 kg a.i./ha), bromophos (0.7 kg a.i./ha), and carbaryl and mollases (1.0 kg a.i./ha) in controlling the grubs of the beetle on brinjal in Hessarrghatta (Karnataka). In Himachal Pradesh, Kumar and Kumar (1995) reported that populations of this beetle collected from 12 vegetable growing areas of the state showed the resistance ratios for malathion to vary from 14.86 to 43.40 when tested against grubs and from 5.50 to 14.02 for adults, respectively. Studies undertaken on the selection of a strain of *E. vigintioctopunctata* resistant to malathion by appling a selection pressure of 60-80 per cent kill in every generation resulted in to 7.79-times resistance to malathion after nine generations of selection (Kumar and Kumar, 1998)

2.2.2.2 Endosulfan

Endosulfan, a commonly used insecticide from cyclodiene group, was introduced in 1956 by Hoechst AG under the trade name, Thiodan (Anonymous, 1979). The earliest report of the development of endosulfan resistance in crop insect- pests is in *Trichoplusia ni* (Hb.). In 1968 growers in Western New York were unable to obtain adequate control of this pest and laboratory studies revealed 3- fold resistance to endosulfan (McEwen and Splittstoesser, 1970). An account of the later reports on the development of endosulfan resistance in insect- pests of crops is given below:

i) *Helicoverpa armigera* (Hb.):

H. armigera was found to develop 3-fold tolerance to endosulfan in Cape Town, South Africa (Whitlock, 1973). Kay (1977) reported 21-fold resistance to endosulfan in a strain of the pest collected from Queensland in `Australia. Ahmad and Mc Caffery (1988) conducted bioassays with a range of insecticides to assess the degree of resistance in a strain of *H. armigera* collected in the fields in Thailand and reported that the Thailand strain had a resistance factor of 2-fold to endosulfan. A moderate (12.5-fold) resistance to endosulfan was reported by Mc Caffery *et al.* (1989) in a strain of this insect collected from cotton fields at Juzzuru in Andhra Pradesh. *H. armigera* collected from cotton growing areas of South Sulawesi, Indonesia in 1988 showed 5.6 - fold resistance to endosulfan (Mc Caffery and Walker, 1991). Low levels of endosulfan resistance (1.92 to 4.13-fold) were reported by Satyavani *et al.* (1991) in populations of the pest collected from Kurnool and Guntur areas of Andhra Pradesh, India. Low levels of resistance (1.15- to 2.18-fold) were also reported from Telangana and Coastal Andhra (Andhra Pradesh) strains of the noctuid by Reddy *et al.* (1991). Mehta *et al.* (1992) studied the comparative resistance of two populations of *H. armigera* from

Gujarat (Anand and Ghuteli) to 5 insecticides and found 2.37-fold resistance to endosulfan in the Ghuteli population as compared to the Anand population. Differential susceptibility of field populations of *H. armigera* to different insecticides was studied by Manoharan and Uthamasamy (1994) in Tamil Nadu. The populations collected from Udumalpat, Coimbatore and Andipatti on cotton and gram showed low to high levels (3- to 31-times) of endosulfan resistance in comparison to a laboratory maintained susceptible population of the pest. Venugopal Rao *et al.* (1994) studied insecticide resistance in *H. armigera* larvae collected from Guntur, Hyderabad, Warangal and Srikakulam regions of Andhra Pradesh during 1990-93. The degree of resistance to endosulfan (estimated by comparing the LC_{90} values of specific strain with the recommended dosage of the insecticide) varied from 14.2 to 109.2-fold in the four strains. Highest resistance factor was recorded in insects collected at Srikakulam from a tomato field sprayed continuously with the insecticide.

Gunning and Easton (1994) studied development of endosulfan resistance in *H. armigera* collected from New South Wales and Queensland from 1974 to 1990. The highest levels of endosulfan resistance (>50-fold) were recorded in 1974 following several years of endosulfan use in the field. Resistance was not detected from 1977 to 1983 when pyrethroids were substituted for endosulfan in the field. However, with the reintroduction of endosulfan the resistance had become wide spread and highest level of resistance recorded after 1984 was 23-fold and laboratory selection with endosulfan increased to 163-fold. Patel *et al.* (2000) reported 3.68 and 2.06- fold resistance to endosulfan for Kayavarohan and Bayad population of *H. armigera* respectively, in Gujrat. Resistance frequency for endosulfan was reported to be 12.5 to 77.8 per cent at Regional Research Station, Lam, Guntur during different periods of cotton crop season for *H. armigera* (Rao *et al.*, 2000)

ii) *Spodoptera litura* (Fab.):

Reddy (1983) reported 4.9-fold resistance in Guntur population of *S. litura* whereas population collected from Tenali (Andhra Pradesh) showed 85.91-fold resistance to endosulfan (Ramakrishnan *et al.*, 1984).

iii) *Bemisia tabaci (Genn.)*:

A strain of the cotton whitefly, *B. tabaci* was found moderately resistant to endosulfan in Sudan (Dittrich and Ernst, 1983). Ahmad *et al.* (1987) reported that when compared with a susceptible strain, the resistance in adults and nymphs of *B. tabaci* was 364- and 5-fold, respectively.

iv) *Lipaphis erysimi* (Kalt.):

Udeaan and Narang (1988) compared susceptibility of different populations of *L. erysmi* collected from different parts of the Punjab to endosufan and reported 24-fold resistance in a population from PAU farm, Ludhiana in comparison to susceptible population collected from Rurka.

v) *Myzus persicae* (Sulz.):

The toxicity of 7 commonly used insecticides to the aphid was investigated and it was reported that since 1967 the LC_{50} of endosulfan had increased 21-times (Dhingra, 1990). Udeaan and Narang (1993) reported emergence of endosulfan resistance in *M. persicae* in different locations of Punjab (India). The authors reported that the populations of the aphid collected during 1988-90 from village Rania, Saiftipur, Dugri, Bhadalwal and Dhandra were 75-, 70.5-, 49-, 31.5 and 30.7-times resistant to endosuflan, respectively compared to the most susceptible population from village Sareenth. In M. *persicae*, Chinnabbai *et al.* (1999)

observed that endosulfan had 750 and 532.8 fold resistance in Guntur and Prakasum populations, respectively in Andhra Pradesh.

vi) *Aphis gossypii* (Glov.):

Three strains of *A. gossypii* collected from cotton fields in Sudan over 3 seasons from 1988 to 1990 were found highly resistant to endosulfan (Gubran *et al.*, 1992). Hillingsworth *et al.* (1994) compared LC_{50} values for sixteen populations of *A. gossypii* from Hawaii and reported upto 3.6-fold resistance to endosulfan. LC_{50} values for endosulfan were positively correlated with the previous use of endosulfan.

vii) *Hypothenemus hampei* (Ferrari):

H. hampei resistance to endosulfan was reported for the first time by Brun *et al.* (1989) from New Caledonia. Out of 16 populations tested for their susceptibility to endosulfan by direct spray method, 5 strains showed high levels (1000-fold) of resistance. Detection of resistance in the pest was due to 10 years of biennial endosulfan application. Brun and Suckling (1992) used a direct spray technique to monitor the frequency of endosulfan resistant *H. hampei* in cofee plantations in New Caledonia that had been sprayed from the road. A rapid decrease in resistance frequency away from the road was evident. Treatment of plantation with 2 applications of endosulfan in a year resulted into 61.4 per cent increase in the frequency of endosulfan resistant phenotypes. Changes in frequency of the resistant phenotypes in the absence of the insecticide suggested that the frequency of endosulfan resistance might not decline rapidly enough to justify its reintroduction within several years.

viii) *Scirtothrips dorsalis* Hood:

The population collected from Guntur and Warrangal were found 4.4-fold and 2.9-fold resistant to endosulfan, respectively (Reddy *et al.*, 1992).

ix) *Leptinotarsa decemlineata* (Say):

Four populations of beetle collected from Ontario were more than 30-fold resistant to endosulfan (Turnbull *et al.*, 1988).

x) *Epilachna vigintioctopunctata* (Fab.):

Kumar and Kumar (1995) found that populations of *E. vigintioctopunctata* collected from 12 vegetable growing areas of the state showed the resistance ratios for endosulfan to vary from 7.08 to 18.54 when tested against grubs and 2.02 to 8.24 for adults, respectively. Studies under taken in the laboratory on the selection of a strain of *E. vigintioctopunctata* resistant to endosulfan by applying a selection pressure of 60-80 per cent kill in every generation resulted in to 6.59- times resistance to endosulfan after 9 generations of selection (Kumar and Kumar, 1997).

2.2.2.3 Fenvalerate:

Fenvalerate was introduced by the Sumitoma Chemical Co. Ltd. in 1972. It is a highly active contact insecticide effective against a broad range of pests including strains resistant to organochlorine, organophosphorus and carbamate insecticides. An account on resistance to insect-pests to fenvalerate is given below:

i) *Lipaphis erysimi* (Kalt.):

Dhingra and Singh (1988) observed that *L. erysimi* had developed 29.4- fold resistance to fenvalerate in Dehradun.

ii) *Leptinotarsa decemlineata* (Say):

Heim *et al.* (1990) registered extensive variation in resistance to several chemicals in *L. decemlineata* from North Carolina and resistance to fenvalerate was most extensive in populations from Carteret and Pamlico countries.

iii) *Helicoverpa armigera* (Hb.):

Reddy *et al.* (1991) studied the development of resistance to fenvalerate using third instar larvae of *H. armigera* collected from Guntur and Rangareddy districts of Andhra Pradesh and found 2.28 and 1.95 times resistance to these insecticides, respectively. Pasupathy and Regupathy (1994) monitored development of insecticide resistance in *H. armigera* collected from several locations in Tamil Nadu and reported prevalence of high level of fenvalerate resistance. Patel *et al.* (2000) reported moderate levels in *H. armigera* of resistance to fenvalerate for Kayavarohan (11.90-fold) and Bayad (6.38-fold) populations of *H. armigera* in Gujrat. Rao *et al.* (2000) monitored insecticide resistance levels in *H. armigera* to fenvalerate at Regional Agricultural Research Station, Lam, Guntur during different periods of cotton crop season. The resistance frequency for the insecticide was found to be 20-95.8 per cent.

iv) *Spodoptera frugiperda* :

Fall armyworms, *Spodoptera frugiperda* (J.E. Smith) in Florida showed 2 to 284 fold resistance to synthetic pyrethroids (Yu, 1991).

v) *Spodoptera litura* (Fab.)

Armes *et al.* (1997) conducted tests on *S. litura* in Andhra Pradesh and reported that resistance level for fenvalerate ranged from 8 to 21- fold.

vi) *Pectinophora gossypiella* (Saunders):

Adult males of *P. gossypiella* from cotton fields in Cixi, Zhejiang Province, China, frequently treated with pyrethroids showed 26 to 28- fold resistance to fenvalerate (Lee *et al.*, 199).

vii) *Aphis gossypii* (Glov.):

In Sudan, three strains of *A. gossypii*, collected from cotton fields were highly resistant to fenvalerate in laboratory tests (Gubran *et al.*, 1992). Sixteen populations of *A. gossypii* from Hawaii showed up to 390- fold resistance to fenvalerate (Hillingsworth *et al.*, 1994). In Japan, resistant clone of *A. gossypii* showed extremely higher level of resistance (16000- fold) to fenvalerate (Saito *et al.*, 1995)

viii) *Mythimna separata* Walk:

In china, Yang *et al.* (1995) collected *M. separata* Walk. from eastern China and found 3.30 to 6.33- fold tolerant to fenvalerate.

2.3 Cross-resistance spectrum of resistant strains

Cross- resistance is a phenomenon whereby a strain of insect develops resistance to two or more insecticides as a result of exposure to one insecticide only. Cross- resistance arises from the presence of a single biochemical or physiological mechanism, which gives protection against several different chemicals usually having a similar mode of toxicological action. As a result of number of studies with resistant strains originating in the field as well as those selected in the laboratory, it has been recognized that the classification of modern organic insecticides on the basis of their chemical constitution coincides closely with a grouping according to the intensity of cross- resistance. The following groups have been recognized (Metcalf, 1955; Hoskins and Gordon, 1956; Brown and Pal, 1971).

Group I: DDT, methoxychlor, DDD, DBrDt DFDT and DEtDT (i.e. DDT and its relatives).

Group II: Gamma-BHC, Heptachlor, Aldrin, Dieldrin, Toxaphene, Chlordane (i.e. polychlorinated aromatics).

Group III: Prolan and Bulan (i.e. nitroethane analogues of DDT).

Group IV: Parathion and other organic phosphates.

Group V: Pyrethrins and allethrins.

Group VI: Lethanes and other thiocyanates.

Group VII: Carbamates.

. These are the basic groups of insecticides divided on the basis of cross- resistance spectrum. Generally speaking, but by no means invariably, the development of resistance to one member of the group involves significant cross- resistance to other members of that group thus, vitiating their values as alternatives. The value of members of other groups is usually un – impaired but the development of resistance to any compound often involves a low level of cross- resistance (sometimes misleadingly called as vigour tolerance) to members of other groups and that may predispose them to the rapid development of resistance on their introduction for control. However, several exceptions to the above generalization have been reported in various species. Busvine (1959) obtained clear evidence in house fly that malathion resistance was different from the resistance to diazinon and parathion and that the strain which had been developed by ma'athion pressure in the field and laboratory showed little cross- resistance to parathion and diazinon. It was also found that in organophosphate and carbamate groups resistance to one compound did not usually extend to more than a few chemically related analogues e.g. resistance of the rice stem borer to parathion did not extend to its methyl analogues (Winteringham, 1966). Winteringham (1966) divided some of the groups and suggested 11 groups to include all the insecticides. FAO enlarged the list to 13 by adding two more groups (Anonymous, 1969). The grouping, however, was reconsidered by a panel of experts of FAO (Anonymous, 1970) and the following classification was proposed:

Ia: DDT and its 1,2-hydrochloro analogues (e.g., methoxychlor)

Ib: DDT analogues whose chemical structures preclude the loss of hydrogen and chlorine atoms attached to the carbon atoms of the ethane moiety (e.g., Dilan).

II: Gamma – BHC (lindane), aldrin, dieldrin, endrin, chlordane, endosulfan, and other cyclodiene insecticides.

IIIa: O-methyl organophosphorus compounds (e.g., methyl parathion, dicapthion).

IIIb: O-ethyl organophosphorus compounds – including some of groups IIIa and IIIb.

IVa: N- methyl carbamates (e.g., arpocarb, carbaryl).

IVb: N- dimethyl carbamates, (e.g., dimetilan).

IVc: Miscellaneous carbamates, including some of groups and IVb.

V: Pyrethroids.

The literature on the cross-resistance spectrum of insecticide resistant strains of insect-pests is reviewed as under:

2.3.1 Diamondback moth, *P. xylostella* (L.):

There are variable reports on the cross-resistance spectrum of strains resistant to organophosphate insecticides. Liu *et al.*, (1981) reported that diazinon- resistant strain (15.1x) of *P. xylostella* showed significant cross-resistance to permethrin (47.6x), cypermethrin (21.2x), decamethrin (25.7x) and fenvalerate (20.8x). They further reported that methomyl resistant strain (2.8x) had slight yet consistent negative cross-resistance to permethrin, cypermethrin and decamethrin except fenvalerate (3.8x). Cheng *et al.* (1985) reported that resistance to some organophosphate compounds could result in the cross-resistance to synthetic pyrethroids. Wang and Feng (1986), however, reported that populations selected for resistance to mevinphos or carbofuran showed decreased cross-resistance to fenvalerate.

Population collected from cabbage field in Japan and found highly resistant to organophosphates, was highly susceptible to cartap and a mixture of fenvalerate and dimethoate (Kimura, 1989). Joia *et al.* (1996) also reported that quinalphos resistance (70 times) in *P. xylostella* did not extend to cartap hydrochloride.

Variable levels of cross-resistance to various insecticides have beenreported in strains resistant to synthetic pyrethroids. Liu *et al.* (1995) reported that deltamethrin resistant (1163-fold) strain of *P. xylostella* had positive cross-resistance to cypermethrin but little cross-resistance to DDVP and methomyl. Wang and Feng (1986) reported that cross-resistance to fenvalerate decreased in populations selected with mevinphos or carbofuran in Taiwan. Cheng and Sun (1986) also reported that selection with fenvalerate showed slight cross-resistance to organophosphorus compound. In field studies carried out in Philippines and Taiwan to overcome resistance to deltamethrin in this pest, deltamethrin tank-mixed with *Bacillus thuringiensis* (1600 IU/mg) and sprayed @ 20 g a.i. with 1000g product / ha, respectively gave satisfactory control of insecticide resistant populations (Yeh *et al.,* 1986). In Japan, highly resistant population to pyrethroid insecticides was found to be very susceptible to chlorfluazuron in both field and laboratory tests (Mizukoshi, 1994). Joia *et al.*, (1996) found that cartap hydrochloride did not show any cross-resistance and was highly toxic to a population of *P. xylostella* resistant to cypermethrin (2800 times) and fenvalerate (2700 times), thus sparing its value as a control measure. The mixture of bifenthrin 1 EC and prothiofos 50 EC in 1:50 ratio was found very effective against insecticides resistant *P. xylostella* which had shown 581-, 18-, 19-, and 11- fold resistance to fenvalerate, cypermethrin, furathiocarb and prothiofos in a Chinju strain (Korean Republic), respectively and 38- and 9- fold resistance to fenvalerate and furathiocarb in a Seosang strain in Korea (Chung *et al.*, 1997).

Sannaveerappanavar and Viraktamath (1997) indicated that flufenoxuron (37.5 g a.i./ha), teflubenzuron (56.25 g ai/ha) and aqueous neem seed kernel extract (4 per cent) were highly effective in suppressing resistance in *P. xylostella* followed by four *B. thuringiensis* products (Biobit @ 500 g/ha, Delfin @ 750 g/ha, Dipel 8L @1125ml/ha and Centari @625 g/ha).

2.3.2 Malathion, endosulfan and fenvalerate resistant strains of other agricultural insect-pests

i) *Nephotettix cincticeps* Uhl:

Kawahara *et al.* (1971) observed that malathion resistant strain of *N. cincticeps* showed cross- resistance ratios of 10, 5 and 2 to 3 to other organophosphates, cartap and carbamates, respectively. Ozaki and Kassai (1971) reported that malathion resistant strain (87-fold) of this pest showed resistance to diazinon, methyl paraxon, fenitroxon, kayaphos, phenthoate and salioxon. Malathion-resistant strain (17-fold) of this pest obtained after selection for 16 generations with malathion was also resistant to phenthoate, parathion and EPN. No cross-resistance to organochlorine or carbamates was detected (Iwata and Hama, 1977). The activity of fenvalerate was reported to be negatively correlated with the degree to which resistance to malathion in *N. cincticeps* had developed (Ozaki and Kassai, 1984).

ii) Nilaparvata lugens Stall:

Sun *et al.* (1984) reported that the populations of the plant hopper collected on rice in Taiwan were found to possess a high level of resistance to malathion. All field collected strains as well as laboratory-selected strains with resistance to malathion showed high levels of resistance to permethrin, though they were susceptible to fenvalerate. Malathion resistant strain (93-fold) of *N. lugens* showed 5- to 26-fold cross-resistance to naled, tetrachlorvinphos, monocrotophos, propaphos, fenthion, fenitrothion, diazinon, isoxanthion, pyridaphenthion,

disulfoton, dimethoate, phenthoate, mecarbom carbaryl, propoxur, XMC and methomyl. No cross- resistance to trichorfon, pyrethrins and organophosphorus compounds such as IBP and edifenphos was found.

iii) *Laodelphax striatellus* (Fall):

L. striatellus strain with 370-fold resistance to malathion was selected with fenvalerate in each generation in the laboratory in Japan (Kassai and Ozaki, 1984). The LD_{50} of malathion decreased markedly during the first 5-6 generations of selection but changed little thereafter. The LD_{50} in the 19^{th} selected generation was about one quarter of that of the parent strain.

iv) *Bemisia tabaci* (Genn):

Horowitz and Ishaaya (1992) reported that a 6-fold resistance in *B. tabaci* to endosulfan, observed in a cotton field, did not alter the tolerance to buprofenzin (an insect growth regulator).

v) *Trialeurodes vaporiorum* (Westw):

Wardlow *et al.* (1972) reported that malathion resistant strain (24 to 31-fold resistant) of *T. vaporiorum* showed 1.5 times resistance to dichlorvos. However, Elhag and Horn (1984) found that there was no cross-resistance to dichlorvos, methomyl, permethrin in malathion resistant strain (55-fold resistant) of *T. vaporiorum.*

vi) *Epilachna vigintioctopunctata* (Fab.):

In Himachal Pradesh, Kumar and Kumar (1998) evaluated cypermethrin, fenvalerate, monocrotophos and carbaryl against the malathion (7.79 x) and endosulfan (6.59 x) resistant strains and reported that the two resistant strains did not show any significant cross- resistance to the test insecticides, thus, sparing their values as effective insecticides against the pest

2.4 Biological characteristics of resistant strains

Selection for resistance to insecticides has often resulted in changes in the biological characteristics of the selected strains (Bielarski *et al.*, 1957; Bhatia and Pradhan, 1968, 1971; Verma and Ram, 1973; Saxena and Bhatia, 1980; Bansode and Bhatia, 1981; Senapati and Satpathy, 1981b; Kumar and Bhatia, 1983; Campanhola *et al.*, 1991; O'Brien and Graves, 1992; Yamada *et al.*, 1993; Kumar and Kumar, 1997a).

Yamada *et al.* (1993) studied in the laboratory the biology and survival rate of two strains of *P. xylostella* derived from two populations collected from Taiwan by rearing in laboratory for 14 and 15 generations, respectively with and without chlorfluazuron selection. The results suggested that strains, which had reacquired high levels of resistance to chlorfluazuron had a higher intrinsic rate of natural increase, shorter generation times and higher reproductive rate than non-selected strains.

Biological studies of the two strains of the cotton boll weevil, *Anthonomus grandis*, one quite susceptible and other highly resistant to endrin, showed no difference in the average number of eggs produced per female per day, duration of larval standing, pupal stage or time required to develop from egg to adult. (Bielarski *et al.*, 1957). However, Thomas and Brazzel (1961) reported significant increase in the total developmental period and significant decrease in the reproductive potential of the endrin resistant strain (100-fold resistant) of the same pest. However, they did not find any difference in the mortality rates, sex ratio, oviposition period or per cent egg hatch between the endrin resistant and susceptible strains of *A. grandis*. Kumar and Kumar (1997a) carried out studies on the comparative biology of the strains of *E. vigintioctopunctata* (Fab.) resistant and susceptible to malathion and endosulfan and found that development of resistance to both the insecticides had adversely affected the biotic

potential of the beetle by having significantly longer developmental period and reduced reproductive potential. Thus, resistant strain had become biologically inferior to the susceptible strain.

MATERIAL AND METHODS

Chapter-III

MATERIAL AND METHODS

The present investigation entitled, "Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)" was carried out in the laboratory of Department of Entomology, CSK HPKV, Palampur from March, 2000 to July, 2001and in the Entomology laboratory, CSK HPKV, Hill Agricultural, Research and Extension Centre, Bajaura from August, 2001 to August, 2002.

The material and methods used during the investigation are given below:

3.1 Chemicals and other materials

The information regarding different insecticides and other chemicals used in the present study has been given in Table 3.1. Other materials used in conducting the present investigation are given below:

Petri dishes (8 cm diameter), volumetric flasks (25, 50, 100 ml capacity), pipettes, measuring cylinders, beakers, plastic jars (10 x 9 cm), insect rearing cages (27x 21x 21 cm^3.), petri dishes (2 cm dia.), chimneys, muslin cloth, plastic tubes (10 x 4 cm), filter papers, heir hygrometer, fresh cabbage leaves, Potter's tower and BOD incubator.

3.2 Preparation of concentrations of the insecticides

Concentrations of malathion, endosulfan and fenvalerate were prepared from their technical grade products by using benzene as solvent and Triton X –100, as emulsifier. The levels of the solvent and emulsifier were fixed at 10 and 0.5 per cent, respectively. Graded

Table 3.1 Insecticides and other chemicals used

Common name	Trade name	Chemical Name	Purity (%)	Source
(A) Insecticides				
Malathion	Technical	O,O-dimethyl-S- (1,2-dicarbeth-oxyethyl) phosphorodithioate	96.30	Hoechst India Ltd . Hans Bhawan Bahadur shah Jafar Marg, New Delhi 110002
	Tagthion	-do-	50 EC	Tropical Agrosystem (India)Ltd. 19, Marshal Road, 4th Floor, Raja Annamalai Building, Chennai-600008
Endosulfan	Technical	6,7,8,9,10, 10-hexachloro-1, 5,5a, 6,9,9a-hexahydro-6, 9 methano-2, 4-3-benzodioxathieprine 3-oxide	92.00	Hindustan Insecticide Ltd. Haechst House, PB 11123, Nariman Point, Bombay 400021
	Thiodan	-do-	35 EC	Hoechst Schering Agro Evo Limited Hoechst-centre, 54/A.M.V. Road Chakala Andheri (E) Mumbai-4000093
Fenvalerate	Technical	Cyno(3-phenoxyphenyl) methyl 4-chloro-α-(1-methyethyl) benzeneacetate	95.90	Gujrat Agro Industrial co-operation Ltd, Dhanbad
	Fenny	-do-	20 EC	Nagarjuna Fertilizers and Chemical Ltd. Nagarjuna Hills, Hyderbad -500482
Cypermethrin	Ripcord	Cyano(3-phenoxyphenyl) methyl 3-(2,2-dichloroethenyl)-2,2-dimethyl=cyclopropane carboxylate	10 EC	Cyanamid Agro Limted, 83/2, Demini, village, Dadra-396191, U.T., Dadra & Nagar Haveli
Monocrotophos	Monocil	O,O,-dimethyl-O-(?-methyl carbamoyl-1-methyl vinyl)-phosphate	36SL	National Organic Chamical industries Ltd, Mafatlal, Centre Nariman point, Bombay 400021
Lambda-Cyhalothrin	Karate	(3-phenoxyphenyl) methyl 3-(2-chloro-3.3.3.- trifluoro-1-propeny)-2,2-dimethylcyclopropanecarboxylate	5 EC	Zeneca Agro Chemicals Limited 28, Dhandayuthanpani, II Street, Kotturpuram, Channai-600085
(B) Other chemicals				
Benzene	Solvent			E. Mark (India) Pvt. Ltd. Worli, Bombay-400018
Triton x-100	Emulsifier, Alkylated aryl polyether alcohol			Laba Chemie Indo austranal Co. PB. NO. 6136, Bombay 400005

emulsion concentrations of malathion, endosulfan and fenvalerate with fixed levels of solvent and the emulsifier were prepared afresh before the conduct of an experiment. These concentrations were prepared from the stock solutions of the three insecticides by making serial dilutions with benzenated-emulsified water. However, for cross-resistance studies, graded concentrations of the insecticides were prepared from their formulated products by using distilled water.

3.2.1 Preparation of stock solution

Stock solutions (1 to 5 %) depending upon the experiments, of malathion, endosulfan and fenvalerate were prepared in benzene on W/V basis from the technical grades of these insecticides. These solutions were kept in a refrigerator at - 4 ^{0}C and were used for the preparation of different concentrations of the insecticides.

3.2.2 Preparation of benzenated emulsified water

Benzenated emulsified water was prepared from distilled water by fixing the level of benzene and emulsifier, Triton X-100, at 10 and 0.5 per cent, respectively. This preparation was used for making serial dilutions of the insecticidal concentrations. Freshly prepared benzenated emulsified water was used whenever dilutions were made.

3.3 Collection of the test insect

About 2 to 4 hundred larvae and pupae of *P. xylostella* were collected from different vegetable growing areas of the state between April and May 2000. Details of different areas from where collections were made and an account on the use of insecticides against the pest in that area are given in Table 3.2.

Table: 3.2 Areas of collection of diamondback moth and insecticides used for the control of insect- pests on cabbage and cauliflower crops in these areas.

District	Location	Insecticides used
Kullu	Kalheli, Garasa and Hurla	Endosulfan, malathion, DDVP, chlorpyriphos, cypermethrin, fenvalerate, carbaryl, monocrotophos and lambda-cyhalothrin
Mandi	Chailchock and Balh	Endosulfan, malathion, DDVP, chlorpyriphos, cypermethrin, fenvalerate, carbaryl, methyl demeton and monocrotophos
Una	Rampur and Santokhgarh	Endosulfan, malathion, DDVP, chlorpyriphos, cypermethrin, fenvalerate, carbaryl, methyl-parathion and monocrotophos
Hamirpur	Nadaun	Carbaryl, malathion, monocrotophos, endosulfan, cypermethrin and fenvalerate
Kangra	Jamanabad and Samloti	Endosulfan, malathion, DDVP, cypermethrin, fenvalerate, carbaryl and monocrotophos
Shimla	Theog, Matyana and Sandhu	Endosulfan, malathion, chlorpyriphos, cypermethrin, fenvalerate, carbaryl, methyl -parathion and monocrotophos

3.4 Rearing of the test insect

The larvae and pupae of *P. xylostella* were collected from different vegetable growing areas of Himachal Pradesh and reared in the laboratory, locality wise, on cabbage leaves to

adult stage. The adults were held in oviposition cages (27 x 21 x 21 cm^3) and provided with 10% sugar solution as food in cotton swabs. An excised leaf of the cabbage plant with its petiole dipped in water in a glass vial was exposed overnight to adults for oviposition. Such leaves were then transferred to glass chimneys (30x20cm) for hatching. The larvae were regularly provided with fresh leaves without removing the infested one so as to enable them to shift to fresh leaves and to improve their survival rate and reduce the handling time considerably. In this way regular supply of the larvae was ensured by exposing fresh leaves at regular intervals. The method of general rearing of the test insect was largely the same as described by Sood *et al.* (1996).

3.5 Method of bioassay

Different parental populations were screened for their susceptibility to malathion, endosulfan and fenvalerate in the third instar larval stage by using direct spray method of bioassay. Same method was used for studies on development of resistance and for cross-resistance studies. In this method, counted number of third instar larvae (10-15 per replication) were released in clean and dry petri dishes (8 cm diameter) which were then sprayed directly under Potter's tower with one ml of freshly prepared required emulsion concentration of the insecticides at a pressure of 2.0 lbs/inch^2 (13.8 KPa). Third instar larvae were selected for bioassay studies to make handling of the culture easy while conducting experiments. Control petridishes were sprayed with one ml of freshly prepared benzenated emulsified water in case of bioassay tests carried out with emulsion concentrations prepared from the technical grade of insecticides (malathion, endosulfan and fenvelerate), while for other insecticides (formulated product), control petri dishes were sprayed with one ml of distilled water only. Initial trials were run to adjust the range of insecticidal concentrations, which give mortality between 10

and 90 per cent. A complete test for each insecticide finally comprised of three replications of 4 -5 concentrations and control. Before spraying, the larvae were preconditioned (starved for 24 hours). The sprayed petri dishes were allowed to dry in shade in laboratory for 15 minutes. After drying, the treated insects were transferred to clean petri dishes and these were provided with fresh cabbage leaves as food. Petri dishes containing treated insects were kept in an incubator at 28 ± 1^0 C temperature and 70 $\pm$5 per cent relative humidity. Mortality counts were taken after 24 hours of treatment and insects which were unable to move were counted as dead.

3.6 Selection for resistance

Different parental populations were found to be statistically similar for their susceptibility to malathion, endosulfan and fenvalerate (Table 4.1.1 to 4.1.39). Therefore, adults of different populations were pooled to form a single population and allowed to breed at random. The first generation progeny of the pooled population, designated as parental generation, was divided in to four separate lines (approx. 500 larvae in each line) for further rearing. These lines were designated as the MS- line (subjected to malathion selection pressure), the ES line (subjected to endosulfan selection pressure), FS line (subjected to fenvalerate selection pressure) and the NS-line (without selection pressure of any of the insecticides). The subsequent generations of these lines were designated as G_1, G_2, G_3,-----, G_{14} generation. Two hundred to three hundred third instar larvae, each of the MS, ES and FS-lines in each generation, were subjected to selection pressure of malathion, endosulfan and fenvalerate, respectively. The process of selection was started in the parental generation and continued up to G_{13} generation. A concentration expected to give mortality between 60-80 per cent was choosen to apply selection pressure. This concentration was worked out from

bioassay tests in each generation. The NS-lines was reared simultaneously without subjecting it to any insecticidal pressure. Larvae (third instar) of the NS- line were also tested for their susceptibility to malathion, endosulfan and fenvalerate in each generation and in the 14th generation this line was designated as susceptible strain (S- strain).

3.6.1 Selection for malathion resistance

For the initial selection of the larvae of the MS-line, a concentration of 0.075 per cent of malathion was applied in the parental generation. This concentration was choosen on the basis of bioassay test (Table 4.2.1). Two hundred third instar larvae were subjected to selection pressure and the survivors (68 larvae) were used to raise the first generation (G_1). The same procedure was adopted for each successive generation upto G_{13}, varying the concentration of malathion according to the bioassay tests. The concentrations used for selection were 0.075 per cent for parental, 0.10 per cent for G_1, 0.15 per cent for G_2, 0.20 cent for G_3 and G_4, 0.30 per cent for G_5, 0.35 per cent for G_6, 0.40 per cent for G_7, 0.60 per cent for G_8, 0.65 per cent for G_9, 0.80 per cent for G_{10}, 1.00 per cent for G_{11} and G_{12}, and 1.15 per cent for G_{13} generation. In the 14th generation, no selection pressure was given and the line thus selected was designated as the malathion - resistant strain (MR-strain) which was used for further studies.

3.6.2 Selection for endosulfan resistance

For the initial selection of the larvae of the ES-line, a concentration of 0.05 per cent of endosulfan was applied in the parental generation. This concentration was choosen on the basis of bioassay test (Table 4.2.1). Three third instar larvae were subjected to selection pressure and the survivors (105 larvae) were used to raise the first generation (G_1). The same procedure was adopted for each successive generation upto G_{13} generation, varying

the concentration of endosulfan according to the bioassay tests. The concentrations used for selection were 0.05 per cent for parental, 0.075 per cent for G_1, 0.10 per cent for G_2, 0.15 cent for G_3, 0.20 per cent for G_4, 0.25 per cent for G_5, 0.30 per cent for G_6, 0.40 per cent for G_7, 0.50 per cent for G_8, 0.60 per cent for G_9, 0.75 per cent for G_{10}, 0.80 per cent for G_{11} and G_{12}, and 0.90 per cent for G_{13} generation. In the 14th generation, no selection pressure was given and the line thus selected was designated as the endosulfan - resistant strain (ER-strain) which was used for further studies.

3.6.3 Selection for fenvalerate resistance

For the initial selection in the parental generation, fenvalerate concentration of 0.015 per cent, choosen on the basis of bioassay test (Table 4.2.1) was applied. Two hundred third instar larvae were subjected to selection pressure and the survivors (78 larvae) were used to raise the first generation (G_1). The same procedure was adopted for each successive generation up to G_{13} generation, varying the concentration of fenvalerate according to the bioassay tests. The concentrations used for selection were 0.015 per cent for parental, 0.020 per cent for G_1 and G_2, 0.025 cent for G_3, 0.050 per cent G_4 and G_5, 0.075 per cent for G_6, 0.10 per cent for G_7 and G_8, 0.15 per cent for G_9 and G_{10}, 0.20 per cent for G_{11} and G_{12}, and 0.25 per cent for G_{13} generation. In the 14th generation, no selection pressure was given and the line thus selected was designated as the fenvalerate - resistant strain (FR-strain) which was used for further studies.

3.7 Cross- resistance

Cross- resistance spectrum of the malathion-resistant (MR-), endosulfan-resistant (ER-) and the fenvalerate-resistant (FR) strains, obtained after 14th generations of selection, was studied by testing toxicity of different insecticides as per details given below against resistant and susceptible strains by using direct spray method of bioassay, details of which have been given in section 3.5 of this chapter. LC_{50} values of different insecticides were estimated for third instar larvae of the MR-, ER-, FR- and S- strains and based upon these values, resistance ratios, were worked out. List of insecticides evaluated against the strains are: -

A) Pyrethroids

i) Cypermethrin

ii) Fenvalerate

iii) Lambda-cyhalothrin

B) Organophosphates

i) Malathion

ii) Monocrotophos

C) Cyclodiene

i) Endosulfan

3.8 Studies on biology

The biology of the MR-, ER- and the FR- strains, obtained after 14th generations of selection with malathion, endosulfan and fenvalerate, respectively, was studied on cabbage leaves in comparison to the susceptible strain (S-strain). These studies were carried at 28 ± 1°C temperature and 70 ± 5 per cent relative humidity. The procedure for studying various biological parameters was as follows:

(i) Egg stage

One pair of adults (male and female) of each strain was released inside a glass chimney (20x30 cm) (n=10) provided with excised leaves of cabbage with petioles dipped in water in a glass tube. These were observed for egg laying. Cabbage leaves containing egg masses of each strain were removed and kept over a moist filter paper in separate petri dishes. Egg masses laid on the walls of chimney were also removed for further studies. The eggs (200-250 eggs of each strain) were observed daily to record the data on hatching. Incubation period and per cent egg survival for each strain were worked out.

(ii) Larval stages

a) First instar:

The newly hatched larvae were kept singly in petri dishes (2 cm. diameter) containing wet blotting paper at the bottom and fresh leaves were provided daily as food. Ten such petri dishes were maintained for recording observations. Each of them was daily observed twice for moulting under binocular microscope. The period between hatching date and the date of first moulting gave the duration of first instar.

b) Second instar:

After the first moulting, the second instar larvae were provided fresh leaves and the moult was gently picked up. The observations were taken twice a day for second moulting. The time lapsed between the dates of first and second moulting indicated the second instar duration.

c) Third instar:

The time lapsed between the second and the third moulting provided the third instar duration.

d) Fourth instar:

Since no moulting was observed after the third moulting and the larvae pupated directly, it indicated that the diamondback moth has only four larval instar. The duration between the date of third moulting and the date of pupation was considered to be the fourth instar duration. The time interval between date of egg hatching and beginning of the pupal instar was recorded as the total larval period.

(iii) Pupal stage

On the very date of pupation of the final instar larvae, the pupae were transferred to the plastic vials (6.5 x 2.0 cm) bearing the corresponding number. These were also observed twice a day for the emergence of adult moths. Total time period between date of pupation and date of moth emergence revealed the pupal period.

(iv) Total developmental period

Total time spent to complete development from egg to adult stage was recorded as total developmental period.

(v) Ovipositional behaviour

For recording observations on pre-oviposition, oviposition periods, fecundity etc., newly emerged moths were released in pairs (males and females) on the excised leaves of cabbage as per the method described by Sood *et al.* (1996). One pair of the moth was released in each glass chimney (30 x 20cm.) with ten replicaties for the experiment. Cotton swabs soaked in 10 per cent sugar solution were kept in each chimney as food for adults. The mouth of each chimney was closed with a piece of muslin cloth held by rubber band. During oviposition period, the eggs were counted cautiously and carefully so as to find out the fecundity of female. The eggs were also laid on the walls of the chimneys. The eggs were

gently detached and kept for subsequent observations. The process continued till the female moth died.

(vi) Survival of different developmental stages

Survival of eggs of different strains was worked out by counting the number of eggs hatched from the total number of eggs (200-250 eggs) kept for recording the hatchability in each strain. Freshly laid eggs of each strain were kept separately in petri dishes (containing moist filter paper) along with leaf pieces on which they were laid. To ascertain the larval and pupal survival of the three strains, 100 just hatched larvae from each strain were reared in petri dishes (10 larvae in each petri dish) by providing the fresh leaves daily up to the adult emergence and observations were recorded on mortality of larvae and pupae.

3.9 Presentation and analysis of data

The average per cent mortality for each concentration was calculated and corrected with Abbot's formula (Abbot, 1925) whenever necessary. This corrected per cent mortality was subjected to probit analysis (Finney, 1971) to find out LC_{50} values for different insecticides. LC_{50} denotes the concentration (g of the insecticide/100 ml) of emulsion calculated to give 50 per cent mortality. The results have been presented in the tables under each experiment. The data have also been presented in the form of log (concentration)- probit mortality graphs with each experiment.

Relative toxicity (RT) of an insecticide to larvae of different populations was worked out by dividing the LC_{50} value of that insecticide to the larvae of different populations by the lowest LC_{50} value of the same insecticide among the populations.

Resistance ratios (RR) of the field-collected populations for the three insecticides were calculated as per method given by Saxena *et al.* (1989). According, LC_{99} values of the

insecticide for different populations were divided with the field recommended concentration of that insecticide. Malathion, endosulfan and fenvalerate are recommended @ 0.05, 0.05 and 0.01 per cent, respectively against diamondback moth in Himachal Pradesh (Anonymous, 2003).

Increase in the level of resistance of MS-, ES- and FS-line to malathion, endosulfan and fenvalerate, respectively, after selection pressure in different generations was calculated by comparing the LC_{50} values for these three lines with the NS line. Similarly, to assess the cross-resistance level, the degree of resistance to an insecticide was calculated as the ratio of the LC_{50} to the resistant strain over that to the susceptible strain.

Data on biological parameter of different strains were analyzed by using completely randomized design (Cochran and Cox, 1963).

RESULTS

RESULTS

The experimental results obtained during the course of investigation entitled "Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)" are presented under the following headings:

4.1 Status of resistance to malathion, endosulfan and fenvalerate in diamondback moth, *P. xylostella* (L.) collected from various vegetable growing localities of Himachal Pradesh.

4.2 Selection for resistance to malathion, endosulfan and fenvalerate in *P. xylostella*

4.3 Cross-resistance pattern of resistant strains of *P. xylostella.*

4.4 Biological characteristics of resistant strains of *P. xylostella.*

4.1 Status of resistance to malathion, endosulfan and fenvalerate in diamondback moth, *P. xylostella* (L.) collected from various vegetable growing localities of Himachal Pradesh.

Different populations of *P. xylostella* collected from various localities of Himachal Pradesh were mass reared in the laboratory localities wise and tested for their susceptibility to malathion, endosulfan and fenvalerate in the third instar larval stage by using direct spray method of bioassay. The results of these tests are presented in the Tables 4.1.1 to 4.1.39.

4.1.1 Malathion: The toxicity data of malathion against 3rd instar larvae collected from different locations of the state showed that LC_{50} of this insecticide varied from 0.0231 to 0.0491 per cent. The LC_{50} values of malathion for the populations collected from Kalheli,

Garasa, Hurla, Chailchock, Balh, Rampur, Santokhgarh, Nadaun, Jamanabad, Samloti, Theog, Matyana and Sandhu were 0.0447, 0.0356, 0.0440, 0.0399, 0.0443, 0.0329, 0.0376, 0.0269, 0.0334, 0.0231, 0.0425, 0.0364, and 0.0491 per cent, respectively. The lowest LC_{50} value (0.0231%) was obtained for population from Samloti locality and highest (0.0 491%) for populations from Sandhu area.

4.1.2 Endosulfan: The LC_{50} values of endosulfan for 3rd instar larvae of different populations varied from 0.0252 to 0.0386 per cent. These values for the populations of *P. xylostella* collected from Kalheli, Garasa, Hurla, Chailchock, Balh, Rampur, Santokhgarh, Nadaun, Jamanabad, Samloti, Theog, Matyana and Sandhu localities were 0.0386, 0.0276, 0.0349, 0.0333, 0.0309, 0.0254, 0.0279, 0.0252, 0.0290, 0.0261, 0.0347, 0.0336 and 0.0352 per cent, respectively.

4.1.3 Fenvalerate: The toxicity data of fenvalerate to the populations of *P. xylostella* collected from various localities showed that the LC_{50} values varied from 0.00708% to Nadaun population to 0.01070% to Balh population. These values for the larvae of the populations collected from Kalheli, Garasa, Hurla, Chailchock, Balh, Rampur, Santokhgarh, Nadaun, Jamanabad, Samloti, Theog, Matyana and Sandhu localities were 0.00972, 0.00794, 0.00901, 0.00752, 0.01070, 0.00875, 0.00969, 0.00708, 0.00747, 0.00783, 0.00983, 0.00899 and 0.00996 per cent, respectively.

Data presented in the Tables 4.1.1 to 4.1.39 and summarised in Tables 5.1.1 to 5.1.3 showed that on the basis of LC_{50} values, different populations of the diamondback moth, *P. xylostella* collected from various vegetable growing localities of Himachal Pradesh did not differ significantly with one another for their susceptibility to malathion, endosulfan and fenvalerate.

Table: 4.1.1 Toxicity of malathion to larvae of *P. xylostella* collected from Kalheli (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	20.00	20.00
0.025	28.89	28.89
0.05	46.67	46.67
0.1	75.56	75.56
0.2	88.89	88.89
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 2.417 (Not heterogeneous at P=0.05) Slope (b) = 1.729 $\pm$ 0.251
Regression equation: y = 1.279x + 2.147 LC_{99} =0.990 per cent
LC_{50}=0.0447per cent Fiducial limits of LC_{50} = 0.0346-0.0578 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.1 (a)

Table: 4.1.2 Toxicity of malathion to larvae of *P. xylostella* collected from Garasa (District Kullu)

Per cent Conc.	Per cent mortality	Per cent Corrected mortality
0.0125	26.67	23.26
0.025	40.00	37.21
0.05	60.00	58.14
0.1	77.78	76.75
0.2	93.33	93.02
Control	4.44	

Results obtained from probit analysis:
χ^2 (3) = 0.716 (Not heterogeneous at P=0.05) Slope (b) = 1.773 $\pm$ 0.242
Regression equation: y = 1.773x + 2.247 LC_{99} = 0.732 per cent
LC_{50}=0.0356 per cent Fiducial limits of LC_{50} = 0.0278-0.0457 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.1 (b)

Table: 4.1.3 Toxicity of malathion to larvae of *P. xylostella* collected from Hurla (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	26.67	21.43
0.025	40.00	35.71
0.05	51.11	47.62
0.1	68.89	66.67
0.2	93.33	92.85
Control	6.67	

Results obtained from probit analysis:
χ^2 (3) = 2.787 (Not heterogeneous at P=0.05) Slope (b) = 1.654 $\pm$ 0.226
Regression equation: y = 1.654x + 2.281 LC_{99} = 1.123 per cent
LC_{50}=0.0440 per cent Fiducial limits of LC_{50} = 0.0340.056 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1. 2 (a)

Table: 4.1.4 Toxicity of malathion to larvae of *P. xylostella* collected from Chailchock (District Mandi)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	13.33	11.36
0.0125	22.22	20.45
0.025	37.78	36.37
0.05	51.11	50.00
0.1	77.78	77.28
0.2	88.89	88.64
Control	2.22	

Results obtained from probit analysis:
χ^2 (4) = 1.320 (Not heterogeneous at P=0.05) Slope (b) = 1.619 $\pm$ 0.192
Regression equation: y = 1.619x + 2.407 LC_{99} = 1.093 per cent
LC_{50}=0.0399 per cent Fiducial limits of LC_{50} = 0.0313-0.0509 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.2 (b)

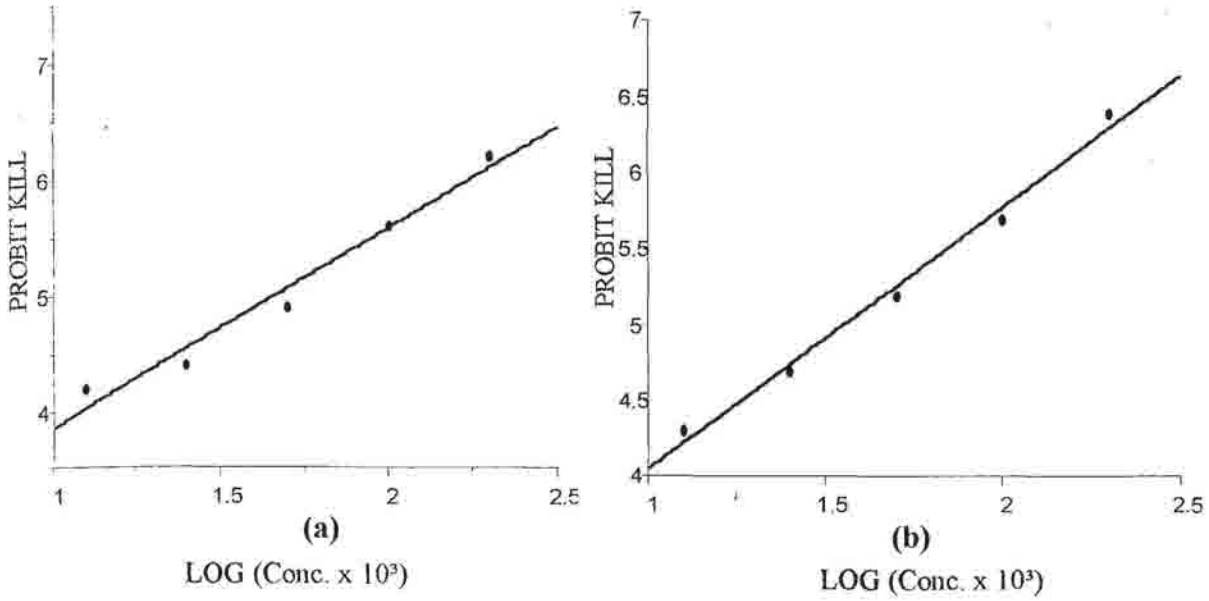


Fig. 4.1.1 Log (conc).- Probit mortality regression lines for malathion to population of *P. xylostella* from Kalheli (a) and Garsa (b).

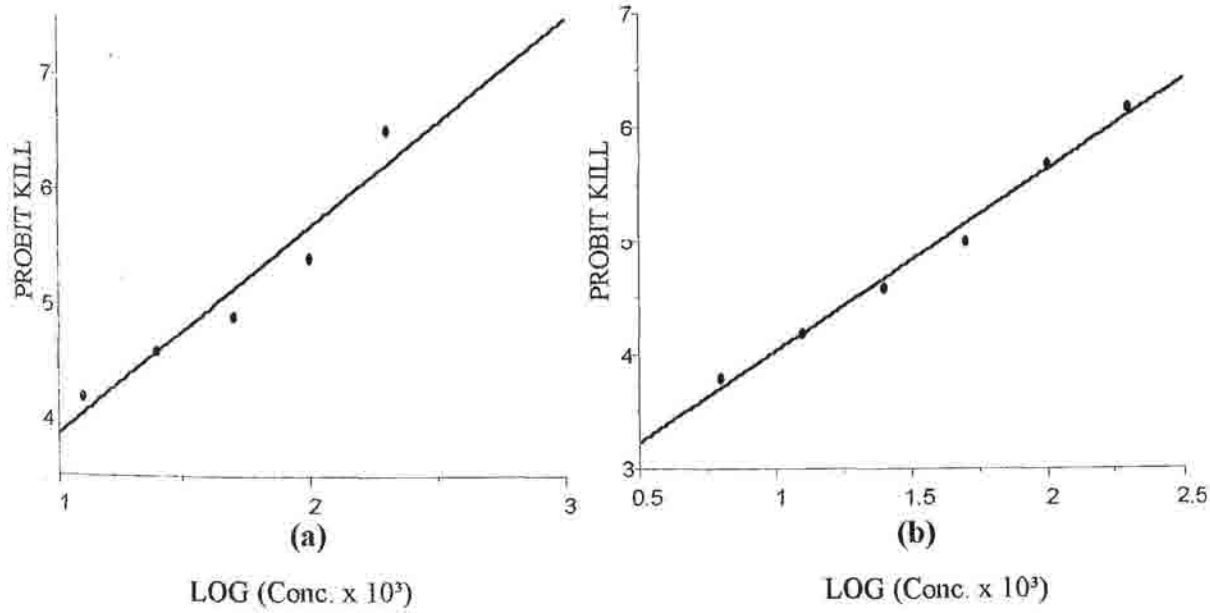


Fig. 4.1.2 Log (conc).- Probit mortality regression lines for malathion to population of *P. xylostella* from Hurla (a) and Chail Chock (b).

Table: 4.1.5 Toxicity of malathion to larvae of *P. xylostella* collected from Balh (District Mandi)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	17.78	17.78
0.025	35.56	35.56
0.05	48.89	48.89
0.1	75.56	75.56
0.2	86.67	86.67
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 0.0237 (Not heterogeneous at P=0.05) Slope (b) = 1.715 $\pm$ 0.237
Regression equation: y = 1.715x + 2.176 LC_{99} = 1.008 per cent
LC_{50}=0.0443 per cent Fiducial limits of LC_{50} = 0.0346-0.0568 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.3 (a)

Table: 4.1.6 Toxicity of malathion to larvae of *P. xylostella* collected from Rampur (District Una)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	24.44	17.07
0.0125	28.89	21.95
0.025	46.67	41.47
0.05	57.78	53.66
0.1	86.67	85.36
Control	8.89	

Results obtained from probit analysis:
χ^2 (3) = 3.171 (Not heterogeneous at P=0.05) Slope (b) = 1.585 $\pm$ 0.221
Regression equation: y = 1.585x + 2.594 LC_{99} = 0.968
LC_{50}=0.0329 per cent Fiducial limits of LC_{50} = 0.0294-0.0503 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.3(b)

Table: 4.1.7 Toxicity of malathion to larvae of *P. xylostella* collected from Santokhgarh (District Una)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	24.44	22.24
0.025	37.78	36.37
0.05	51.11	50.00
0.1	82.22	81.81
0.2	93.33	93.17
Control	2.22	

Results obtained from probit analysis:
χ^2 (3) = 3.255 (Not heterogeneous at P=0.05) Slope (b) = 1.844 $\pm$ 0.243
Regression equation: y = 1.844x + 2.096 LC_{99} = 0.686 per cent
LC_{50}=0.0376 per cent Fiducial limits of LC_{50} = 0.0297-0.0476 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1. 4 (a)

Table: 4.1.8 Toxicity of malathion to larvae of *P. xylostella* collected from Nadaun (District Hamirpur)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	13.33	13.33
0.0125	35.56	35.56
0.025	44.44	44.44
0.05	68.89	68.89
0.1	80.00	80.00
Control	0.00	0.00

Results obtained from probit analysis:
χ^2 (3) = 1.386 (Not heterogeneous at P=0.05) Slope (b) = 1.564 $\pm$ 0.227
Regression equation: y = 1.564x + 2.762 LC_{99} = 0.827 per cent
LC_{50}=0.0269 per cent Fiducial limits of LC_{50} = 0.0207-0.0350 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.4 (b)

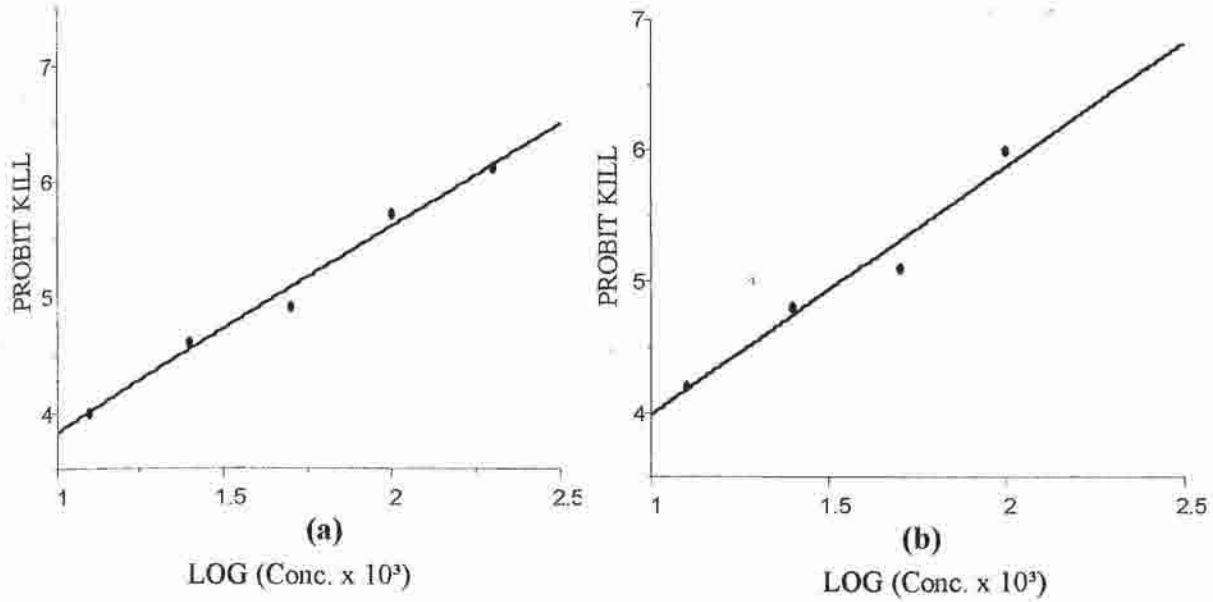


Fig. 4.1.3 Log (conc).- Probit mortality regression lines for malathion to population of *P. xylostella* from Balh (a) and Rampur (b).

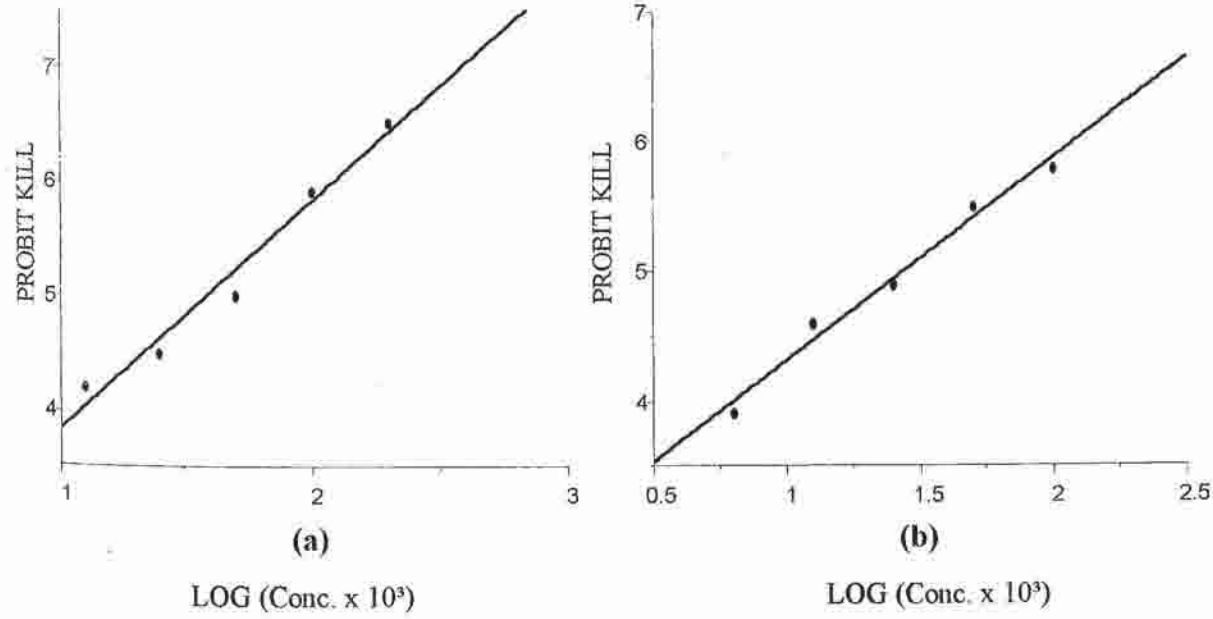


Fig. 4.1.4 Log (conc).- Probit mortality regression lines for malathion to population of *P. xylostella* from Santogarh (a) and Nadaun (b).

Table: 4.1.9 Toxicity of malathion to larvae of *P. xylostella* collected from Jamanabad (District Kangra)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	24.44	17.07
0.0125	31.11	24.39
0.025	44.44	39.02
0.05	57.78	53.66
0.1	84.44	82.92
Control	8.89	

Results obtained from probit analysis:

χ^2 (3) = 1.258 (Not heterogeneous at P=0.05) Slope (b) = 1.688 $\pm$ 0.234
Regression equation: y = 1.688x + 2.429 LC_{99} =0.797 per cent
LC_{50}=0.0334 per cent Fiducial limits of LC_{50} = 0.0271 - 0.0473 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.5 (a)

Table: 4.1.10 Toxicity of malathion to larvae of *P. xylostella* collected from Samloti (District Kangra)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	17.78	13.96
0.0125	42.22	39.54
0.025	48.89	46.52
0.05	73.33	72.09
0.1	84.44	83.72
Control	4.44	

Results obtained from probit analysis:
χ^2 (3) = 1.928 (Not heterogeneous at P=0.05) Slope (b) = 1.515 $\pm$ 0.260
Regression equation: y= 1.515x + 2.934 LC_{99} = 0.793
LC_{50}=0.0231 per cent Fiducial limits of LC_{50} = 0.0173 - 0.0389 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.5 (b)

Table: 4.1.11 Toxicity of malathion to larvae of *P. xylostella* collected from Theog (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	20.00	84.09
0.025	40.00	77.28
0.05	51.11	50.00
0.1	77.78	38.64
0.2	84.44	18.18
Control	2.22	

Results obtained from probit analysis:
χ^2 (3) = 1.338 (Not heterogeneous at P=0.05) Slope (b) = 1.578± 0.246
Regression equation: y= 1.578x + 2.430 LC_{99} = 1.267 per cent
LC_{50}=0.0425 per cent Fiducial limits of LC_{50} = 0.0324-0.0558 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.6 (a)

Table: 4.1.12 Toxicity of malathion to larvae of *P. xylostella* collected from Matyana (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	16.67	14.63
0.0125	31.00	24.39
0.025	44.44	39.02
0.05	62.22	58.53
0.1	80.00	78.05
Control	8.89	

Results obtained from probit analysis:
χ^2 (3) = 0.526 (Not heterogeneous at P=0.05) Slope (b) = 1.548 ± 0.253
Regression equation: y= 1.548x + 2.584 LC_{99} = 1.157 per cent
LC_{50}=0.0364 per cent Fiducial limits of LC_{50} = 0.0270 - 0.0483 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.6 (b)

Table: 4.1.13 Toxicity of malathion to larvae of *P. xylostella* collected from Sandhu (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	15.56	15.56
0.025	35.56	35.56
0.05	48.89	48.89
0.1	66.67	66.67
0.2	84.44	84.44
Control	0.00	

Results obtained from probit analysis:

χ^2 (3) = 0.437 (Not heterogeneous at P=0.05) Slope (b) = 1.574 $\pm$ 0.173

Regression equation: y= 1.574x + 2.334 LC_{99} = 1.486 per cent

LC_{50}=0.0491 per cent Fiducial limits of LC_{50} = 0.0320 - 0.0642 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.6 (c)

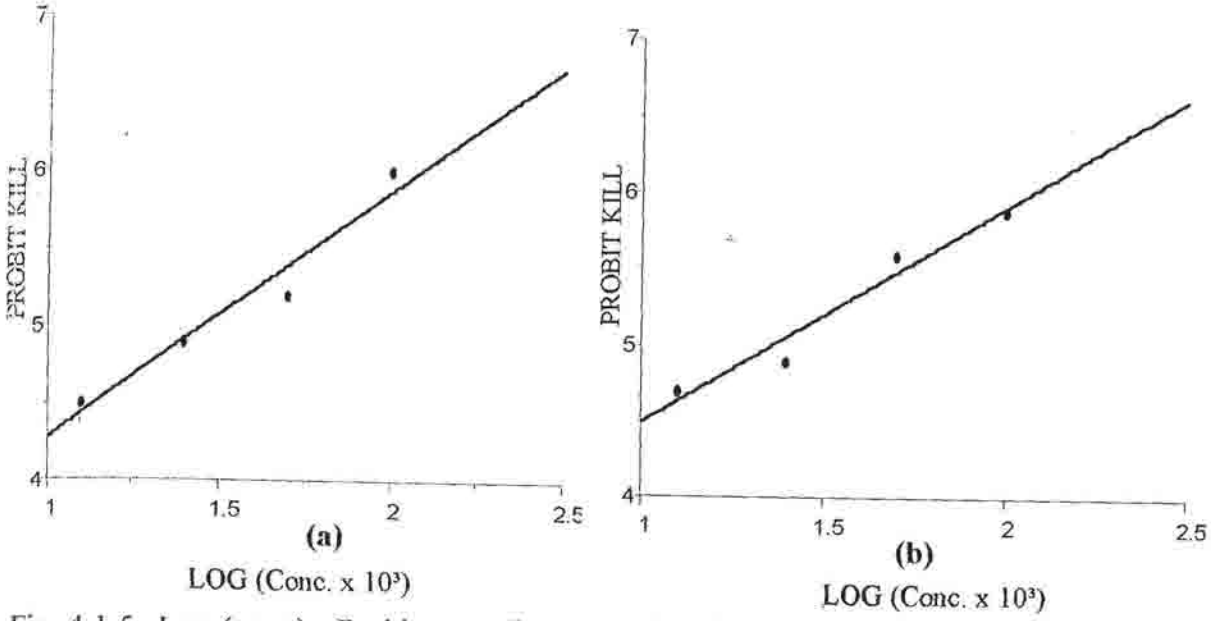


Fig. 4.1.5 Log (conc).- Probit mortality regression lines for malathion to population of *P. xylostella* from Jamanabad (a) and Samloti (b).

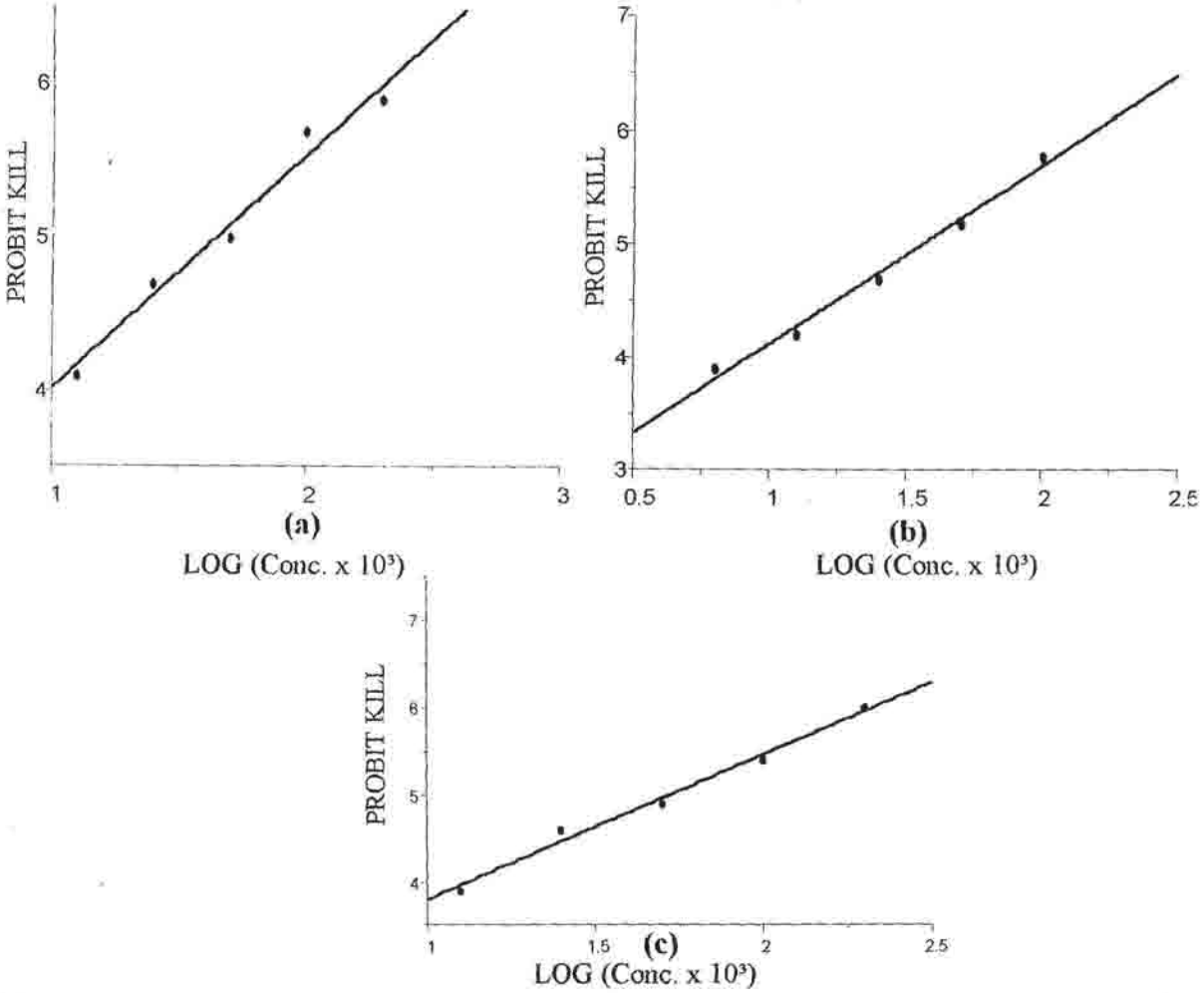


Fig. 4.1.6 Log (conc).- Probit mortality regression lines for malathion to population of *P. xylostella* from Theog (a) and Matyana (b) and Sandhu (c).

Table: 4.1.14 Toxicity of endosulfan to larvae of *P. xylostella* collected from Kalheli (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	24.44	14.99
0.0125	28.89	20.00
0.025	37.78	30.00
0.05	55.56	50.00
0.1	82.22	80.00
0.2	93.33	50.00
Control	11.11	

Results obtained from probit analysis:
χ^2 (4) = 5.210 (Not heterogeneous at P=0.05) Slope (b) = 1.686 $\pm$ 0.188
Regression equation: y= 1.686x + 2.324 LC_{99} = 0.928 per cent
LC_{50}=0.0386 per cent Fiducial limits of LC_{50} = 0.0306-0.0487 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.7 (a)

Table: 4.1.15 Toxicity of endosulfan to larvae of *P. xylostella* collected from Garasa (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	15.56	11.62
0.0125	37.78	34.89
0.025	44.44	41.85
0.05	71.11	69.76
0.1	82.22	81.39
Control	4.44	

Results obtained from probit analysis:
χ^2 (3) = 1.947 (Not heterogeneous at P=0.05) Slope (b) = 1.659 $\pm$ 0.227
Regression equation: y= 1.659x + 2.608 LC_{99} = 0.698 per cent
LC_{50}=0.0276 per cent Fiducial limits of LC_{50} = 0.0216-0.0354 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.7 (b)

Table: 4.1.16 Toxicity of endosulfan to larvae of *P. xylostella* collected from Hurla (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	17.78	13.96
0.0125	24.44	20.93
0.025	42.22	39.54
0.05	53.33	51.16
0.1	84.44	83.71
0.2	93.33	93.02
Control	4.44	

Results obtained from probit analysis:
χ^2 (4) = 3.005 (Not heterogeneous at P=0.05) Slope (b) = 1.704 $\pm$ 0.179
Regression equation: y= 1.704x + 2.370 LC_{99} =0.810 per cent
LC_{50}=0.0349 per cent Fiducial limits of LC_{50} = 0.0279-0.0437 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.8 (a)

Table: 4.1.17 Toxicity of endosulfan to larvae of *P. xylostella* collected from Chailchock (District Mandi)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	17.78	13.96
0.0125	28.89	25.59
0.025	35.56	32.56
0.05	66.67	65.12
0.1	80.00	79.07
0.2	91.11	90.70
Control	4.44	

Results obtained from probit analysis:
χ^2 (4) = 2.281 (Not heterogeneous at P=0.05) Slope (b) = 1.656 $\pm$ 0.194
Regression equation: y= 1.656x + 2.477 LC_{99} = 0.848 per cent
LC_{50}=0.0333 per cent Fiducial limits of LC_{50} = 0.0262-0.0423 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.8 (b)

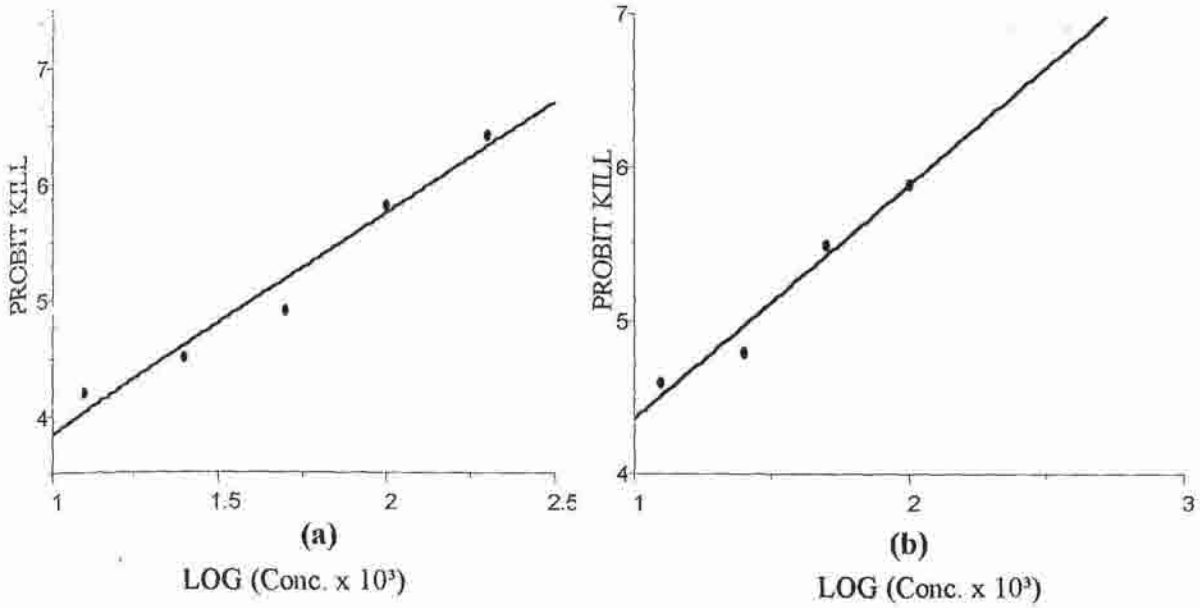


Fig. 4.1.7 Log (conc).- Probit mortality regression lines for endosulfan to population of *P. xylostella* from Kalheli (a) and Garasa (b).

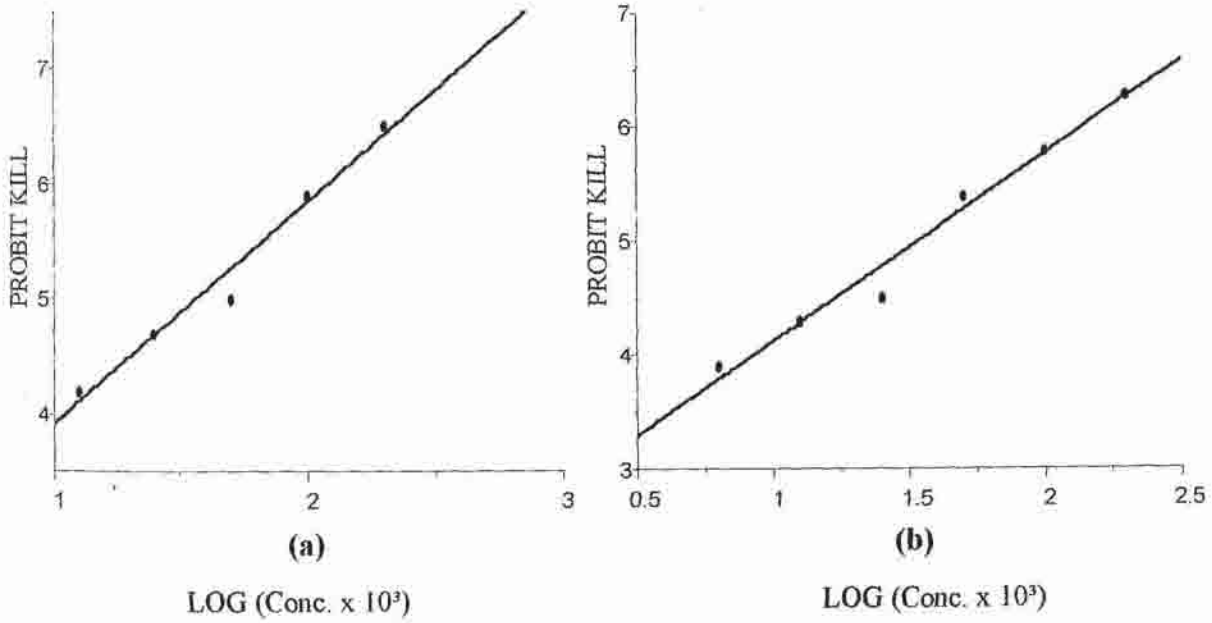


Fig. 4.1.8 Log (conc).- Probit mortality regression lines for endosulfan to population of *P. xylostella* from Hurla (a) and Chail Chock (b).

Table: 4.1.18 Toxicity of endosulfan to larvae of *P. xylostella* collected from Balh (District Mandi)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	20.00	14.28
0.0125	31.11	26.19
0.025	37.78	33.33
0.05	68.89	66.67
0.1	82.22	80.00
Control	6.67	

Results obtained from probit analysis:
χ^2 (3) = 3.538 (Not heterogeneous at P=0.05) Slope (b) = 1.551 $\pm$ 0.257
Regression equation: y= 1.551x + 2.689 LC_{99} = 0.977 per cent
LC_{50}=0.0309 per cent Fiducial limits of LC_{50} = 0.0233-0.0409 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.9 (a)

Table: 4.1.19 Toxicity of endosulfan to larvae of *P. xylostella* collected from Rampur (District Una)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	20.00	16.28
0.0125	33.33	30.23
0.025	48.89	46.56
0.05	73.33	72.09
0.1	84.44	83.71
Control	4.44	

Results obtained from probit analysis:
χ^2 (3) = 0.405 (Not heterogeneous at P=0.05) Slope (b) = 1.683 $\pm$ 0.227
Regression equation: y= 1.683x + 2.636 LC_{99} = 0.612 per cent
LC_{50}=0.0254 per cent Fiducial limits of LC_{50} = 0.0199-0.0332 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1. 9 (b)

Table: 4.1.20 Toxicity of endosulfan to larvae of *P. xylostella* collected from Santokhgarh (District Una)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	17.78	17.78
0.0125	24.44	24.44
0.025	44.44	44.44
0.05	66.67	66.67
0.1	82.22	82.22
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 1.602 (Not heterogeneous at P=0.05) Slope (b) = 1.548 $\pm$ 0.249
Regression equation: y= 1.548x + 2.763 LC_{99} = 0.887 per cent
LC_{50}=0.0279 per cent Fiducial limits of LC_{50} = 0.0211-0.0368 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.10 (a)

Table: 4.1.21 Toxicity of endosulfan to larvae of *P. xylostella* collected from Nadaun (District Hamirpur)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	15.56	15.56
0.0125	24.44	24.44
0.025	42.22	42.22
0.05	75.56	75.56
0.1	88.89	88.89
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 1.579(Not heterogeneous at P=0.05) Slope (b) = 1.959 $\pm$ 0.241
Regression equation: y= 1.959xX + 2.254 LC_{99} = 0.388 per cent
LC_{50}=0.0252 per cent Fiducial limits of LC_{50} = 0.0203-0.0310 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.10 (b)

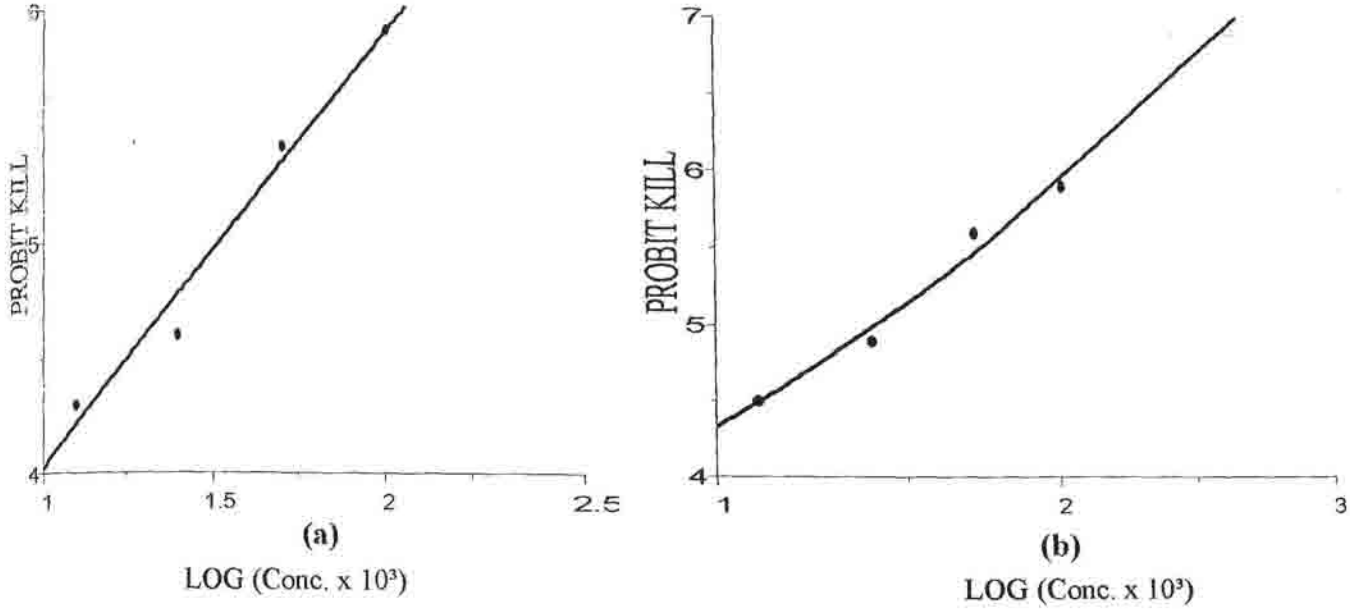


Fig. 4.1.9 Log (conc).- Probit mortality regression lines for endosulfan to population of *P. xylostella* from Balh (a) and Rampur (b).

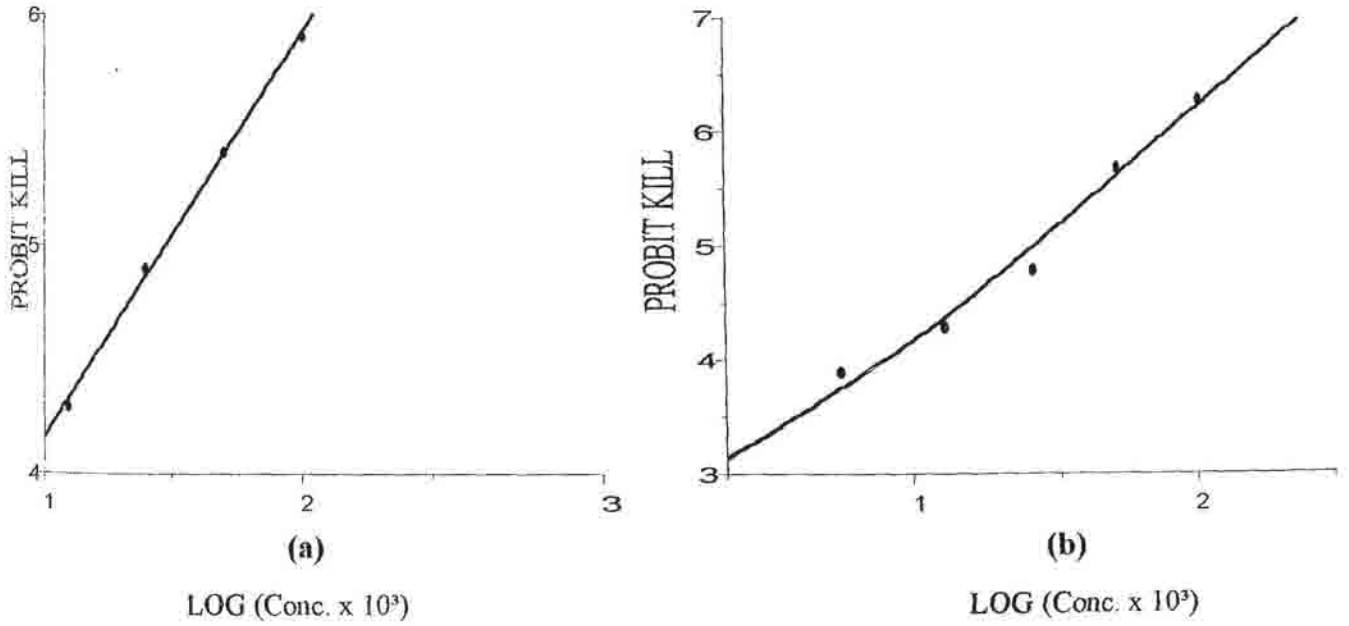


Fig. 4.1.10 Log (conc).- Probit mortality regression lines for endosulfan to population of *P. xylostella* from Santogarh (a) and Nadaun (b).

Table: 4.1.22 Toxicity of endosulfan to larvae of *P. xylostella* collected from Jamanabad (District Kangra)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	24.44	24.44
0.025	44.44	44.44
0.05	68.89	68.89
0.1	84.44	84.44
0.2	93.33	93.33
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 0.142 (Not heterogeneous at P=0.05) Slope (b) = 1.857 $\pm$ 0.783
Regression equation: y= 1.857x + 2.282 LC_{99} = 0.520 per cent
LC_{50}=0.0290 per cent Fiducial limits of LC_{50} = 0.0227-0.0373 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.11 (a)

Table: 4.1.23 Toxicity of endosulfan to larvae of *P. xylostella* collected from Samloti (District Kangra)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	17.78	17.78
0.0125	26.67	26.67
0.025	48.89	48.89
0.05	71.11	71.11
0.1	86.67	86.67
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 0.0112 (Not heterogeneous at P=0.05) Slope (b) = 1.923$\pm$ 0.321
Regression equation: y= 1.923x + 2.275 LC_{99} = 0.423 per cent
LC_{50}=0.0261 per cent Fiducial limits of LC_{50} = 0.0189-0.0358 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.11 (b)

Table: 4.1.24 Toxicity of endosulfan to larvae of *P. xylostella* collected from Theog (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	15.56	15.56
0.0125	37.78	37.78
0.025	48.89	48.89
0.05	60.00	60.00
0.1	82.22	82.22
Control	0.00	0.00

Results obtained from probit analysis:
χ^2 (3) = 3.563 (Not heterogeneous at P=0.05) Slope (b) = 1.696 $\pm$ 0.201
Regression equation: y= 1.696 X + 2.384 LC_{99} = 0.821 per cent
LC_{50}=0.0347 per cent Fiducial limits of LC_{50} = 0.0262-0.0450 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.12 (a)

Table: 4.1.25 Toxicity of endosulfan to larvae of *P. xylostella* collected from Matyana (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00625	22.22	18.61
0.0125	28.89	25.59
0.025	37.78	34.89
0.05	53.33	51.16
0.1	82.22	81.39
0.2	93.33	93.02
Control	4.44	

Results obtained from probit analysis:
χ^2 (4) = 5.203 (Not heterogeneous at P=0.05) Slope (b) = 1.555 $\pm$ 0.200
Regression equation: y= 1.555x + 2.626 LC_{99} = 1.054 per cent
LC_{50}=0.0336 Fiducial limits of LC_{50} = 0.026-0.0431 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.12 (b)

Table: 4.1.26 Toxicity of endosulfan to larvae of *P. xylostella* collected from Sandhu (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	20.00	20.00
0.025	44.44	44.44
0.05	57.78	57.78
0.1	80.00	80.00
0.2	88.89	88.89
Control	0.00	

Results obtained from probit analysis:

χ^2 (3) = 0.766 (Not heterogeneous at P=0.05) Slope (b) = 1.697 $\pm$ 0.232

Regression equation: y= 1.697x + 2.375 LC_{99} = 0.827

LC_{50}=0.0352 per cent Fiducial limits of LC_{50} = 0.027-0.0454 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.12 (c)

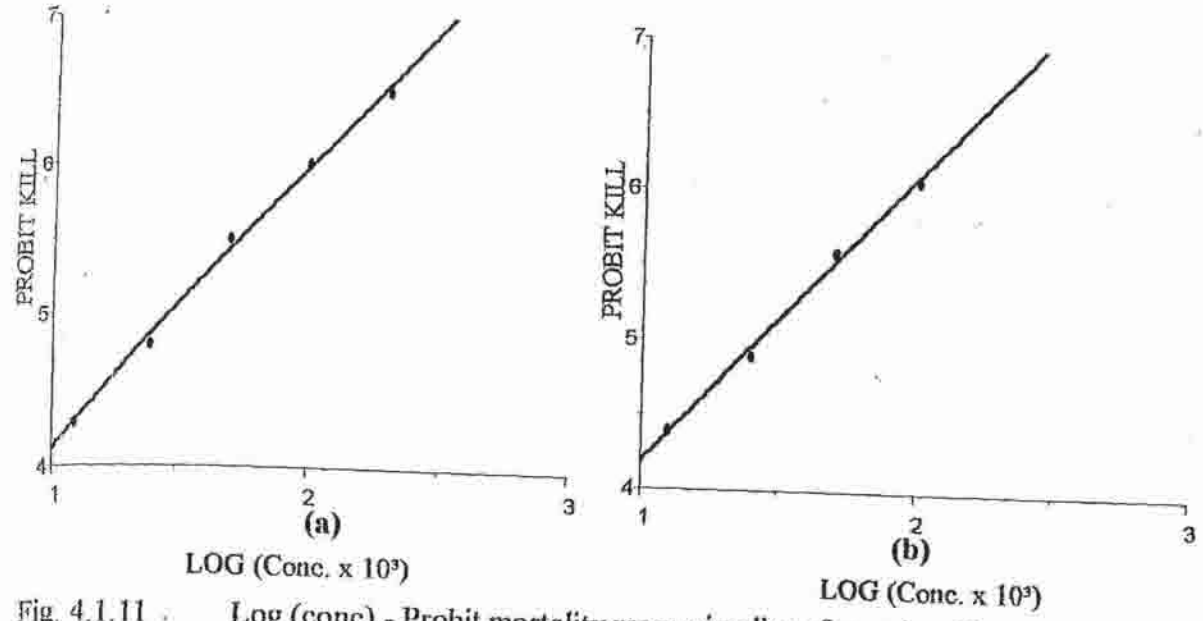


Fig. 4.1.11 Log (conc).- Probit mortality regression lines for endosulfan to population of *P. xylostella* from Jamanabad (a) and Samloti (b).

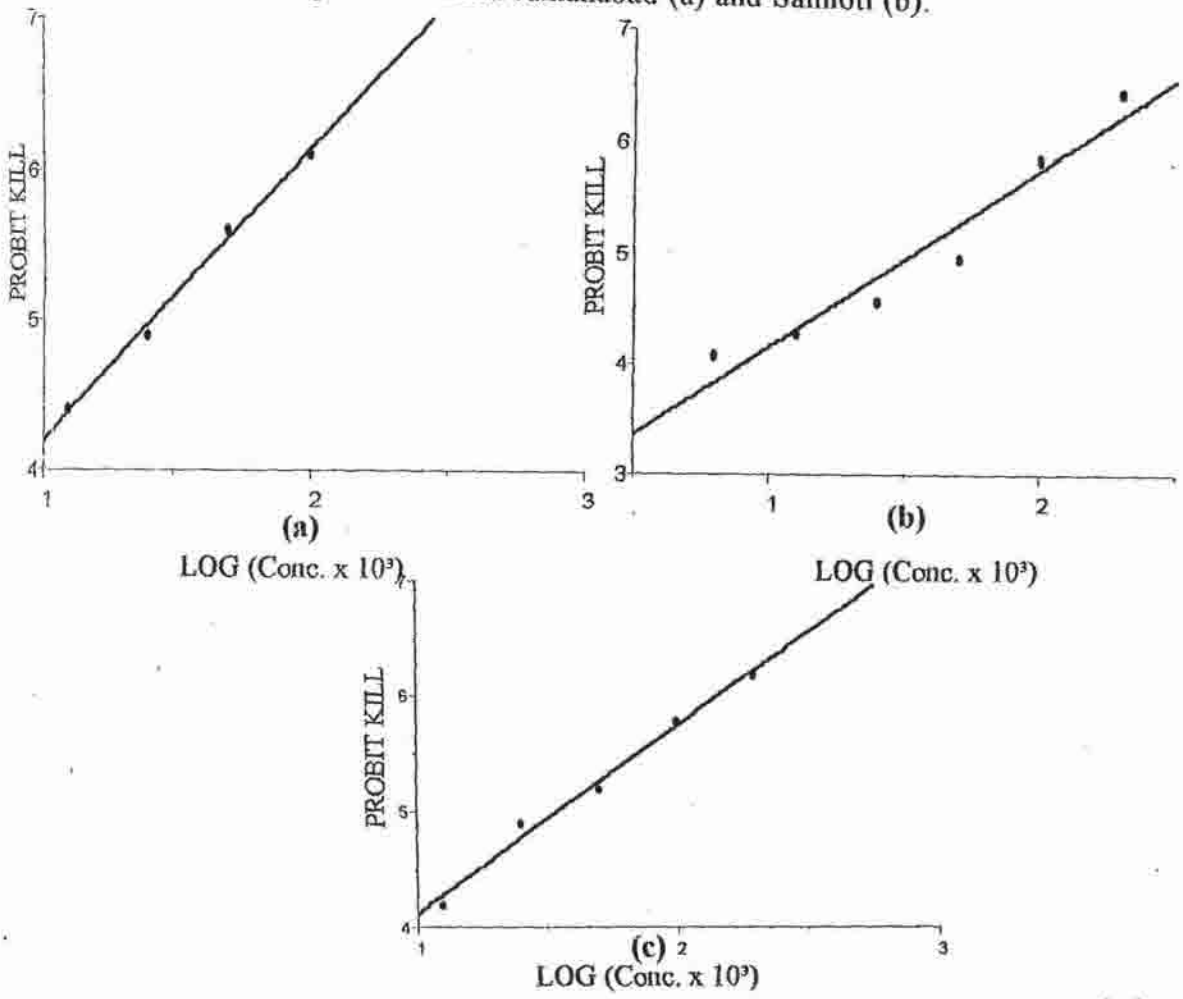


Fig. 4.1.12 Log (conc).- Probit mortality regression lines for endosulfan to population of *P. xylostella* from Theog (a) and Matyana (b) and Sandhu (c).

Table: 4.1.27 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Kalheli (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	15.56	15.56
0.005	35.56	35.56
0.01	46.67	46.67
0.02	71.11	71.11
0.04	84.44	84.44
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 0.659 (Not heterogeneous at P=0.05) Slope (b) = 1.653 $\pm$ 0.229
Regression equation: y= 1.653x + 3.367 LC_{99} = 0.248 per cent
LC_{50}=0.00972 per cent Fiducial limits of LC_{50} = 0.00758-0.01247 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.13 (a)

Table: 4.1.28 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Garasa (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	24.44	24.44
0.005	35.56	35.56
0.01	51.11	51.11
0.02	75.56	75.56
0.04	88.89	88.89
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 1.002 (Not heterogeneous at P=0.05) Slope (b) = 1.591 $\pm$ 0.223
Regression equation: y= 1.591x + 3.568 LC_{99} = 0.231 per cent
LC_{50}=0.00794 per cent Fiducial limits of LC_{50} = 0.00612-0.01033 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.13 (b)

Table: 4.1.29 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Hurla (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	22.22	16.67
0.005	42.22	38.09
0.01	53.33	50.00
0.02	73.33	71.42
0.04	86.67	85.71
Control	6.67	

Results obtained from probit analysis:
χ^2 (3) = 0.581 (Not heterogeneous at P=0.05) Slope (b) = 1.631 $\pm$ 0.229
Regression equation: y= 1.631x + 3.443 LC_{99} = 0.241 per cent
LC_{50}=0.00901 per cent Fiducial limits of LC_{50} = 0.00699-0.01161 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.14 (a)

Table: 4.1.30 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Chailchock (District Mandi)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	28.89	25.58
0.005	40.00	37.21
0.01	53.33	51.16
0.02	77.78	76.75
0.04	91.11	90.70
Control	4.44	

Results obtained from probit analysis:
χ^2 (3) = 1.608 (Not heterogeneous at P=0.05) Slope (b) = 1.625 $\pm$ 0.230
Regression equation: y= 1.625x + 3.575 LC_{99} = 0.203 per cent
LC_{50}=0.00752 per cent Fiducial limits of LC_{50} = 0.00579-0.00978 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.14 (b)

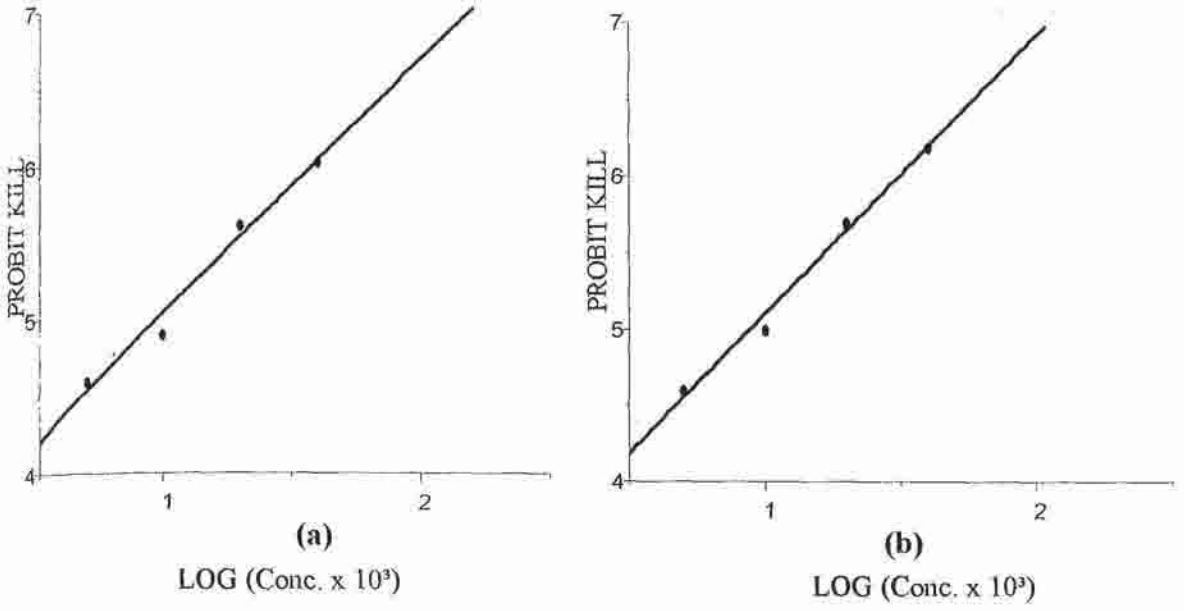


Fig. 4.1.13 Log (conc).- Probit mortality regression lines for fenvalerate to population of *P. xylostella* from Kalheli (a) and Garasa (b).

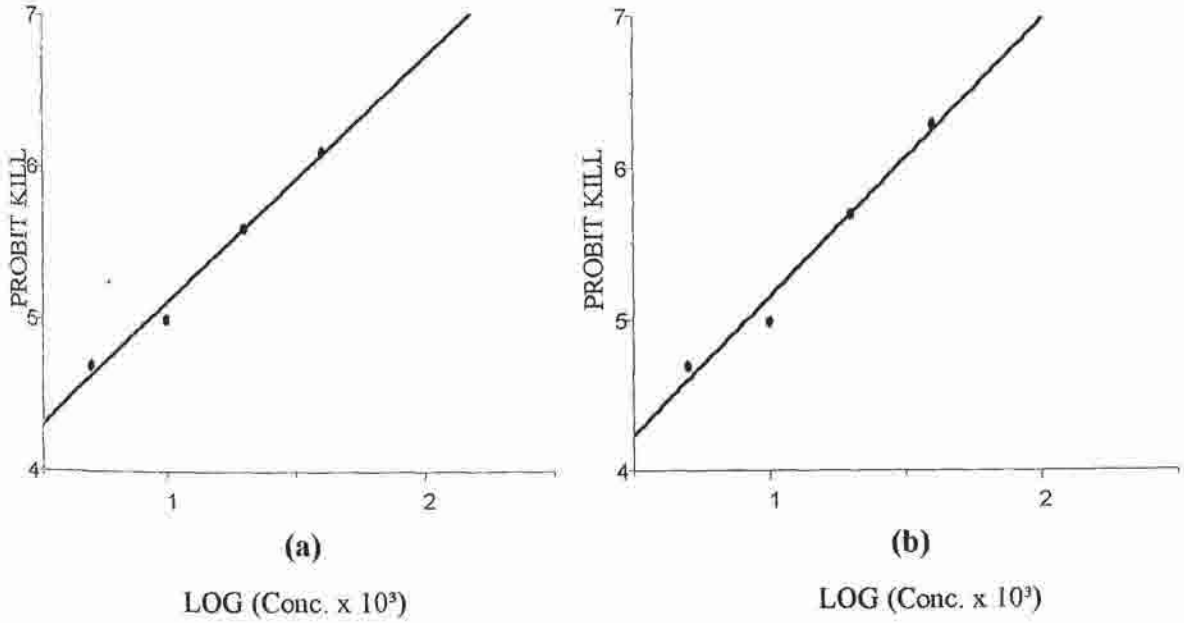


Fig. 4.1.14 Log (conc).- Probit mortality regression lines for fenvalerate to population of *P. xylostella* from Hurla (a) and Chail Chock (b).

Table: 4.1.31 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Balh (District Mandi)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	13.33	13.33
0.005	33.33	33.33
0.01	44.44	44.44
0.02	68.89	68.89
0.04	82.22	82.22
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 0.779 (Not heterogeneous at P=0.05) Slope (b) = 1.648 $\pm$ 0.230
Regression equation: y= 1.648x + 3.303 LC_{99} = 0.276 per cent
LC_{50}=0.01070 per cent Fiducial limits of LC_{50} = 0.00834-0.01375 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.15 (a)

Table: 4.1.32 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Rampur (District Una)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00312	24.44	20.93
0.00625	48.89	46.52
0.0125	55.56	53.49
0.025	82.22	81.39
Control	4.44	

Results obtained from probit analysis:
χ^2 (2) =1.888 (Not heterogeneous at P=0.05) Slope (b) = 1.706 $\pm$ 0.303
Regression equation: y= 1.706x + 2.241 LC_{99} = 0.202 per cent
LC_{50}=0.00875 per cent Fiducial limits of LC_{50} = 0.00675-0.01134 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.15 (b)

Table: 4.1.33 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Santokhgarh (District Una)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	20.00	14.28
0.005	28.89	23.81
0.01	37.77	33.33
0.02	55.56	52.38
0.04	80.00	78.57
Control	6.67	

Results obtained from probit analysis:
χ^2 (3) = 2.066 (Not heterogeneous at P=0.05) Slope (b) = 1.479 $\pm$ 0.233
Regression equation: y= 1.479x + 3.539 LC_{99} = 0.362 per cent
LC_{50}=0.00969 per cent Fiducial limits of LC_{50} =0.00724-0.01299 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1. 16 (a)

Table: 4.1.34 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Nadaun (District Hamirpur)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	20.00	20.00
0.005	46.67	46.67
0.01	55.56	55.56
0.02	75.56	75.56
0.04	86.67	86.67
Control	0.00	

Results obtained from probit analysis:
χ^2 (3) = 1.697 (Not heterogeneous at P=0.05) Slope (b) = 1.460 $\pm$ 0.179
Regression equation: y= 1.460x + 3.758 LC_{99} = 0.278 per cent
LC_{50}=0.00708 per cent Fiducial limits of LC_{50} =0.00458-0.01094 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.16 (b)

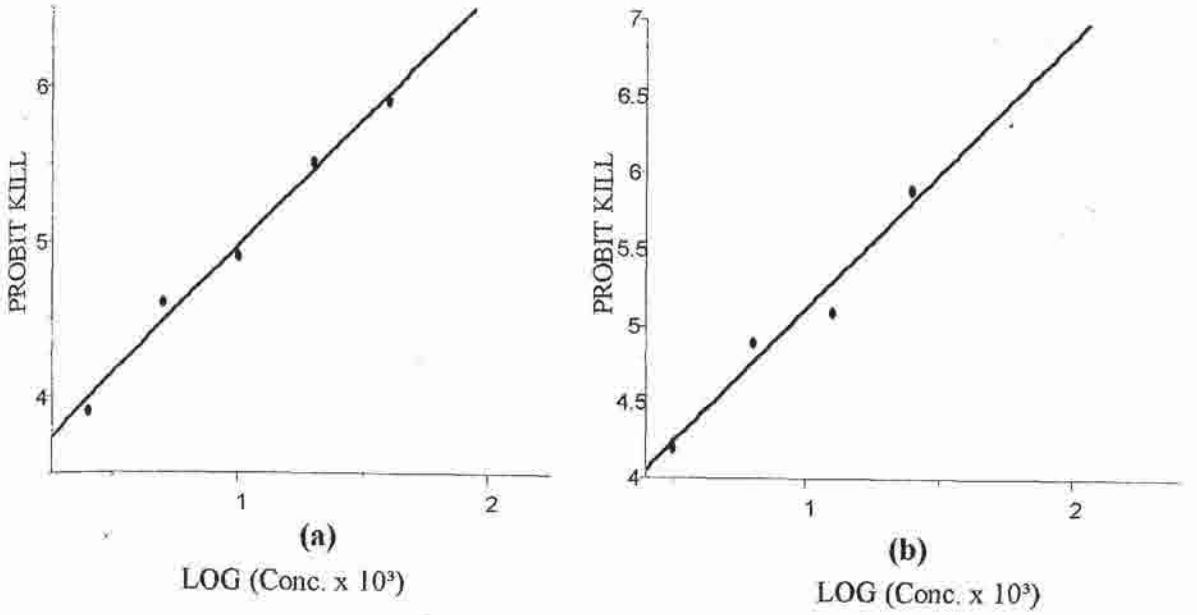


Fig. 4.1.15 Log (conc) - Probit mortality regression lines for fenvalerate to population of *P. xylostella* from Balh (a) and Rampur (b).

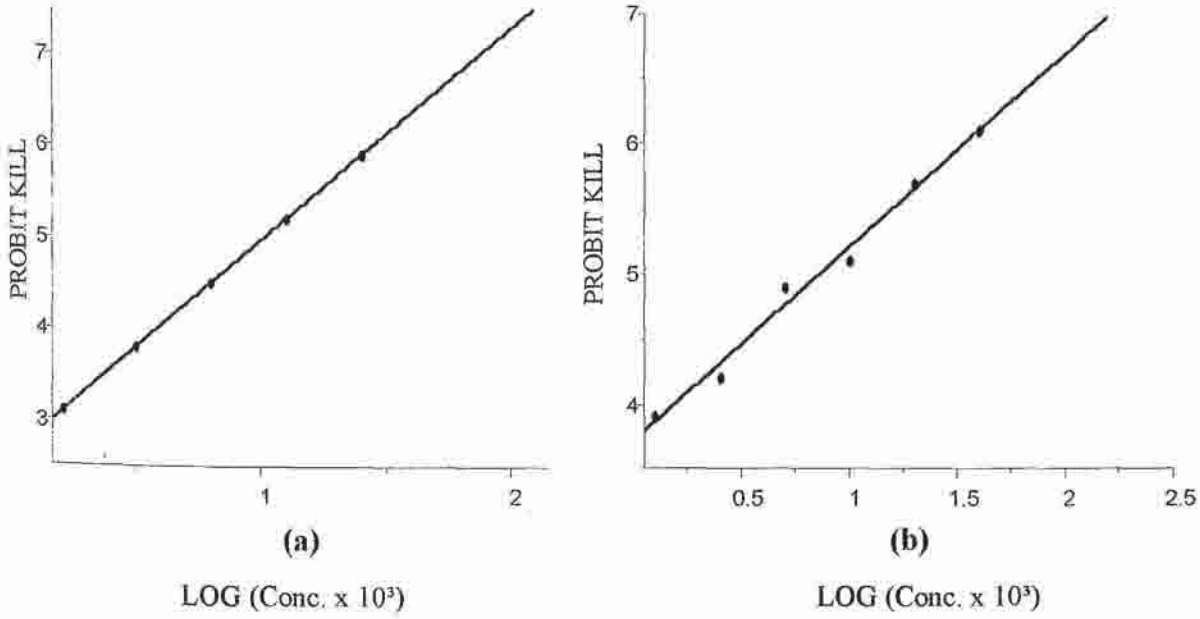


Fig. 4.1.16 Log (conc).- Probit mortality regression lines for fenvalerate to population of *P. xylostella* from Santogarh (a) and Nadaun (b).

Table: 4.1.35 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Jamanabad (District Kangra)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00125	15.56	15.56
0.0025	24.44	24.44
0.005	33.33	33.33
0.01	51.11	51.11
0.02	77.78	77.78
0.04	88.89	88.89
Control	0.00	

Results obtained from probit analysis:
χ^2 (4) = 3.091 (Not heterogeneous at P=0.05) Slope (b) = 1.497 $\pm$ 0.188
Regression equation: y= 1.497x + 3.692 LC_{99} = 0.267 per cent
LC_{50}=0.00747 per cent Fiducial limits of LC_{50} = 0.00482-0.01159 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.17 (a)

Table: 4.1.36 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Samloti (District Kangra)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.00156	20.00	14.28
0.00312	26.67	21.42
0.00625	51.11	46.62
0.0125	57.78	54.76
0.025	84.44	83.33
Control	6.67	

Results obtained from probit analysis:
χ^2 (3) = 3.356 (Not heterogeneous at P=0.05) Slope (b) = 1.524 $\pm$ 0.261
Regression equation: y= 1.524x + 3.638 LC_{99} = 0.263 per cent
LC_{50}=0.00783 per cent Fiducial limits of LC_{50} = 0.00587-0.01045 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.17(b)

Table: 4.1.37 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Theog (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	20.00	18.18
0.005	37.78	36.37
0.01	46.67	45.46
0.02	68.89	68.18
0.04	82.22	81.82
Control	2.22	

Results obtained from probit analysis:
χ^2 (3) = 0.348 (Not heterogeneous at P=0.05) Slope (b) = 1.587 $\pm$ 0.238
Regression equation: y= 1.587x + 3.425 LC_{99} = 0.287 per cent
LC_{50}=0.00983 per cent Fiducial limits of LC_{50} = 0.00751-0.01280 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.18 (a)

Table: 4.1.38 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Matyana (District Kullu)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	22.22	14.63
0.005	40.00	34.15
0.01	51.11	46.34
0.02	73.33	70.73
0.04	86.67	85.37
Control	8.89	

Results obtained from probit analysis:
χ^2 (3) = 0.119 (Not heterogeneous at P=0.05) Slope (b) = 1.577 $\pm$ 0.262
Regression equation: y= 1.577x + 3.495 LC_{99} = 0.269 per cent
LC_{50}=0.00899 per cent Fiducial limits of LC_{50} = 0.00677-0.01196 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.18 (b)

Table: 4.1.39 Toxicity of fenvalerate to larvae of *P. xylostella* collected from Sandhu (District Shimla)

Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0025	20.00	14.28
0.005	40.00	35.72
0.01	51.11	47.62
0.02	71.11	69.05
0.04	84.44	83.33
Control	6.67	

Results obtained from probit analysis:
χ^2 (3) = 0.794 (Not heterogeneous at P=0.05) Slope (b) = 1.558 $\pm$ 0.234
Regression equation: y= 1.558x + 3.445 LC_{99} = 0.310 per cent
LC_{50}=0.00996 per cent Fiducial limits of LC_{50} = 0.00760-0.01305 per cent

The log (Concentration)-probit mortality regression line is presented in Fig. 4.1.18 (c)

Data presented in Tables 5.1.1 and 5.1.3 also showed that population collected from Samloti area was the most susceptible to malathion while populations from other selected areas were 1.165 to 2.126 times less susceptible to malathion as compared to Samloti population. For endosulfan and fenvalerate, population from Nadaun area was the most susceptible. In comparison to the toxicity of these insecticides to Nadaun population, populations from other areas were 1.008 to 1.532 and 1.055 to 1.511 times less susceptible to endosulfan and fenvalerate, respectively.

4.2 Selection for resistance to malathion, endosulfan and fenvalerate in *P. xylostella*

Data presented in the Tables 4.1.1. to 4.1.39 showed that populations of *P. xylostella* collected from various localities of the state did not differ with one another for their susceptibility to malathion, endosulfan and fenvalerate on the basis of LC_{50} values. Therefore,

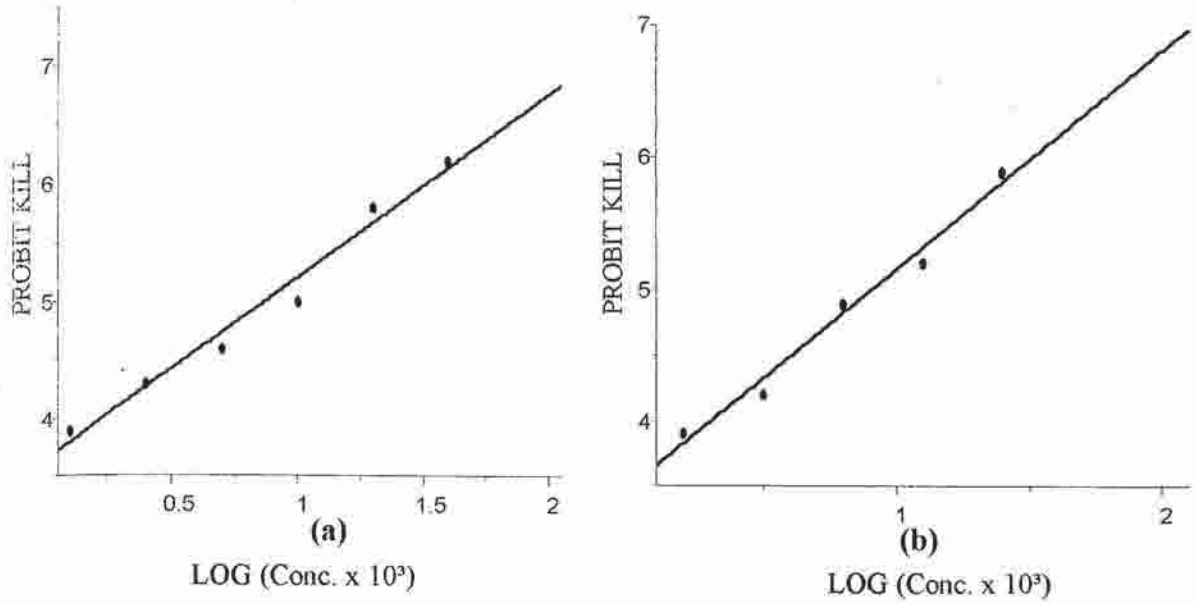


Fig. 4.1.17 Log (conc).- Probit mortality regression lines for fenvalerate to population of *P. xylostella* from Jamanabad (a) and Samloti (b).

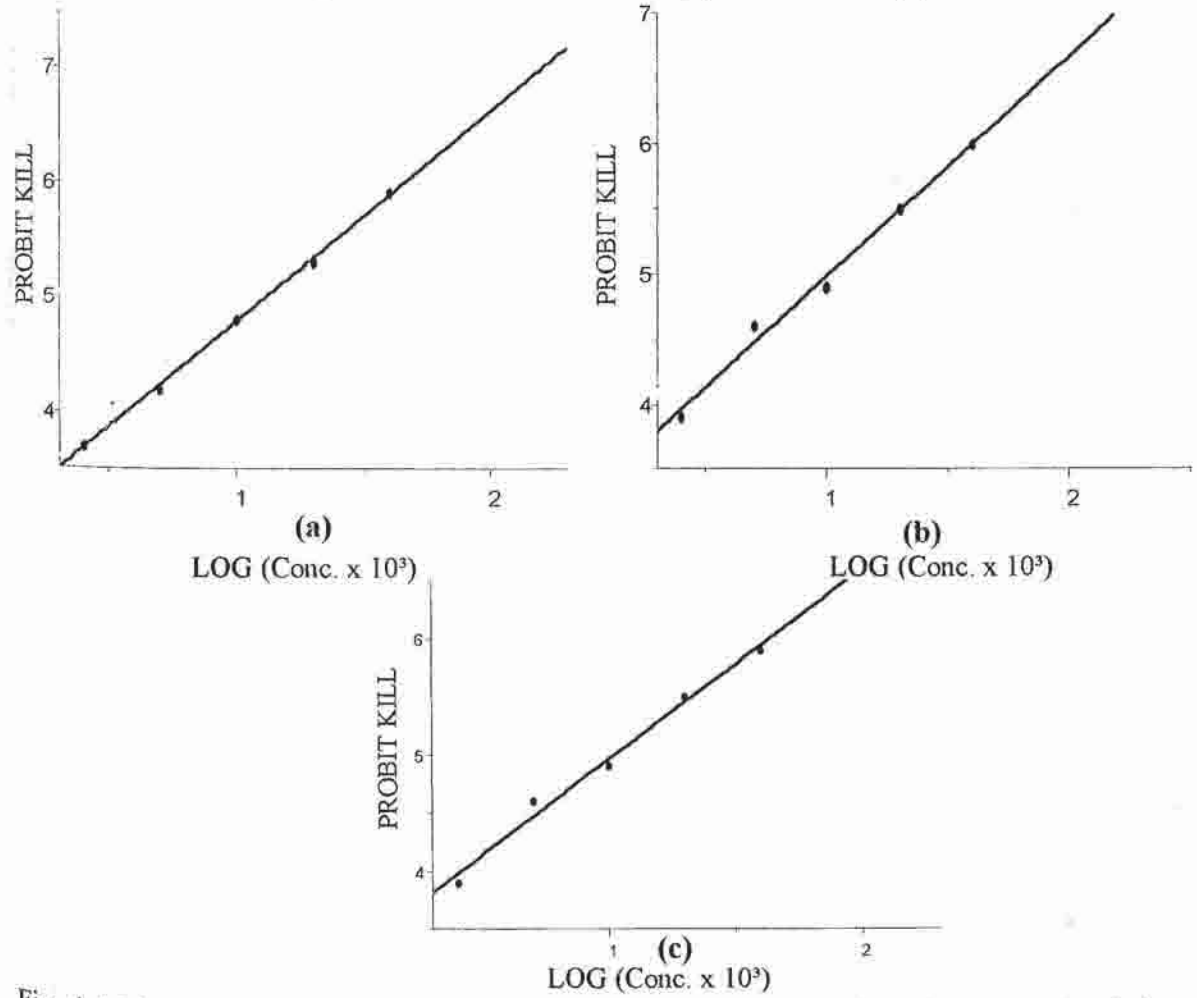


Fig. 4.1.18 Log (conc).- Probit mortality regression lines for fenvalerate to population of *P. xylostella* from Theog (a) and Matyana (b) and Sandhu (c).

adults of different populations were pooled to form a single population and allowed to breed *ad lib*. The first generation progeny of the pooled population, designated as parental generation, was divided into four separate lines for further rearing. These lines were designated as the MS-line, the ES-line, the FS-line and the NS-line. The MS-, ES- and FS-lines were subjected to selection pressure (concentration giving 60-80 % kill) of malathion, endosulfan and fenvalerate, respectively in each generation to find out that after how many generations of selection pressure the pest would develop resistance to these insecticides.

4.2.1 Selection with malathion

Data (Table 4.2.1 to 4.2.15) showed that concentrations of malathion used for applying selection pressure of 60-80 per cent kill to the 3rd instar larvae were 0.075, 0.10, 0.15, 0.20, 0.20, 0.30, 0.35, 0.40, 0.60, 0.65, 0.80, 1.00, 1.00 and 1.15 per cent in the parental, G_1, G_2, G_3, G_4, G_5, G_6, G_7, G_8, G_9, G_{10}, G_{11}, G_{12} and G_{13} generations, respectively. Thus, beginning with a concentration of 0.075 per cent of malathion in the parental generation, a concentration of 1.15 per cent (15.33 times more than the initial concentration) was achieved in the 13th generation to cause a selection pressure of 60-80 per cent kill of the 3rd instar larvae. The LC_{50} values of malathion were 0.043, 0.052, 0.071, 0.087, 0.109, 0.159, 0.179, 0.238, 0.318, 0.491,0.532, 0.685, 0.776, 0.814 and 0.847 per cent for the larvae of the MS-line in the parental and subsequent generations, respectively. In case of NS line, the LC_{50} values of malathion were 0.041, 0.039, 0.042, 0.040, 0.038, 0.037, 0.038, 0.039, 0.038, 0.034, 0.036, 0.035, 0.033 and 0.031 per cent for the larvae of respective generations. After 14th generations of selection pressure, LC_{50} value of malathion for the 3rd instar larvae of the MS- line was found to be 27.32-fold more than the NS-line. The LC_{50} values of malathion for the MS- and the NS-lines in the parental and subsequent generations showed non-significant differences

between the two lines up to G_2. The difference between the two lines for their susceptibility to malathion was evident in G_3 and subsequent generations.

4.2.2 Selection with endosulfan:

For selection with endosulfan, concentrations used to cause a selection pressure of 60-80 per cent kill of the 3rd instar larvae were 0.05, 0.075, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.75, 0.80, 0.80 and 0.90 per cent in the parental, G_1, G_2, G_3, G_4, G_5, G_6, G_7, G_8, G_9, G_{10}, G_{11}, G_{12} and G_{13} generations, respectively (Table 4.2.16 and 5.2.1). The concentrations of endosulfan used for selection pressure thus varied from 0.05 per cent in the parental generation to 0.90 per cent in the 13th generation, which is 18.00 times more than the initial concentration.

The LC_{50} values of endosulfan for the larvae of the ES-lines in the parental and subsequent generations were 0.035, 0.039, 0.068, 0.077, 0.094, 0.132, 0.182, 0.240, 0.293, 0.409, 0.528, 0.586, 0.634, 0.662 and 0.689 per cent, respectively. For larvae of the NS-line, the LC_{50} values for endosulfan were 0.033, 0.031, 0.032, 0.030, 0.027, 0.029, 0.030, 0.029, 0.028, 0.026, 0.029, 0.025, 0.024, and 0.023 in the respective generations (Table 4.2.16 and 5.2.3). Thus after 14th generation of selection with endosulfan, the LC_{50} values of endosulfan increased to 29.96-fold for larvae of the ES-line when compared with the NS-line. Comparison of LC_{50} values for ES- and NS- lines in parental and subsequent generations showed that there were no significant differences between the two lines for their susceptibility to endosulfan up to G_1. Differences between two lines for their susceptibility to endosulfan started appearing in G_2 and became evident in subsequent generations.

4.2.3 Selection with fenvalerate:

In case of fenvalerate, concentrations used for applying selection pressure of 60-80 per cent kill of the 3rd instar larvae were 0.015, 0.020, 0.020, 0.025, 0.050, 0.050, 0.075, 0.10, 0.10, 0.15, 0.15, 0.020, 0.020, and 0.025 per cent in the parental, G_1, G_2, G_3,G_4, G_5, G_6, G_7, G_8, G_9, G_{10}, G_{11}, G_{12} and G_{13} generations, respectively (Table 5.2.1). The concentration of fenvalerate used in the parental generation to cause a selection pressure of 60-80 per cent kill of the 3rd instar larvae thus varied from 0.015 per cent to 0.25 per cent (16.67 times more than the initial concentration) in the 13th generation. The LC_{50} values of fenvalerate were 0.00961, 0.00979, 0.01185, 0.01384, 0.01965, 0.02343, 0.03074, 0.04109, 0.04862, 0.06689, 0.09055, 0.09366, 0.10355, 0.10806 and 0.10409 per cent for the larvae of the FS- line in the parental and subsequent generations, respectively. In case of NS-line, the LC_{50} values of fenvalerate were 0.00953, 0.00947, 0.00916, 0.00804, 0.00844, 0.00765, 0.00763, 0.00723, 0.00707, 0.00700, 0.00674, 0.00700, 0.00541 and 0.00567 per cent for the larvae of respective generations (Table 4.2.30 to 4.2.43 and 5.2.4). Thus, after 14th generation (parental and G_1 to G_{13}) of the selection, the LC_{50} values of fenvalerate for the larvae of the FS-line was found to be 19.06-fold more in comparison to the NS-line. The LC_{50} values for FS- and NS- lines in parental and subsequent generations showed that there were no significant differences between the two lines for their susceptibility to fenvalerate up to G_3. In G_4, differences between the FS- and the NS- lines for their susceptibility to fenvalerate were significant and these differences became much evident in the subsequent generations.

Data (Table 5.2.1 to 5.2.4) thus showed that selection with malathion, endosulfan and fenvalerate for fourteen generations (Parental and G_1 to G_{13}) resulted in to strains which were 27.32, 29.96 and 19.06 times resistant, to respective insecticides. Development of resistant to

Table: 4.2.1 Toxicity of malathion, endosulfan and fenvalerate to 3rd instar larvae of *P. xylostella* in parental generation.

	Malathion			Endosulfan			Fenvalerate	
Per cent Conc.	Per cent mortality	Per cent corrected mortality	Per cent Conc.	Per cent mortality	Per cent corrected mortality	Per cent Conc.	Per cent mortality	Per cent corrected mortality
0.0125	24.44	24.44	0.00625	24.44	20.92	0.0025	26.67	19.51
0.025	31.11	31.11	0.0125	35.56	32.56	0.005	37.78	31.70
0.05	55.56	55.56	0.025	53.33	51.16	0.01	55.56	51.22
0.1	68.89	68.89	0.05	64.44	62.78	0.02	66.67	63.42
0.2	86.67	86.67	0.1	73.33	72.09	0.04	88.89	87.81
Control	0.00		0.2	88.89	88.36	Control	8.89	
			Control	4.44				

Results obtained from probit analysis:

Malathion

χ^2 (3) = 1.199 (Not heterogeneous at P=0.05) Slope (b) = 1.512 $\pm$ 0.223

Regression equation: y = 1.512 X + 2.534

LC_{50}=0.043 per cent Fiducial limits of LC_{50} = 0.033-0.057 per cent

Endosulfan

χ^2 (3) = 5.107(Not heterogeneous at P=0.05) Slope (b) = 1.201 $\pm$ 0.169

Regression equation: y = 1.201 X + 3.151

LC_{50}=0.035 per cent Fiducial limits of LC_{50} = 0.026-0.047 per cent

Fenvalerate

χ^2 (4) = 1.288 (Not heterogeneous at P=0.05) Slope (b) = 1.589 $\pm$ 0.226

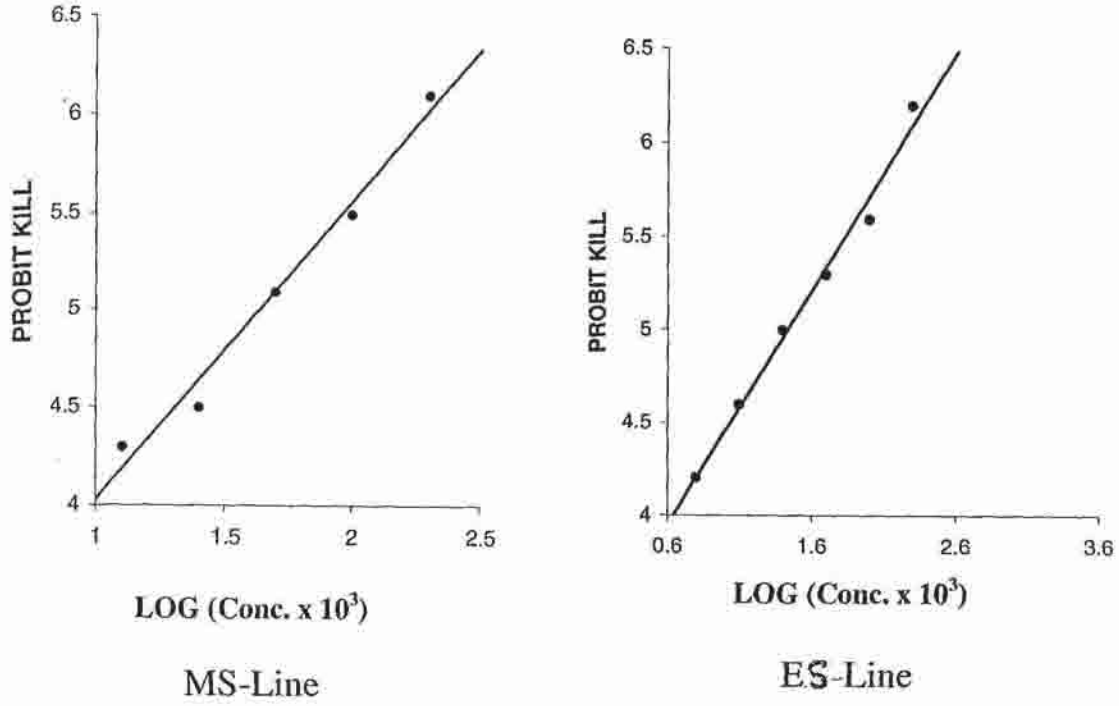
Regression eqution : y = 1.589 X + 3.434

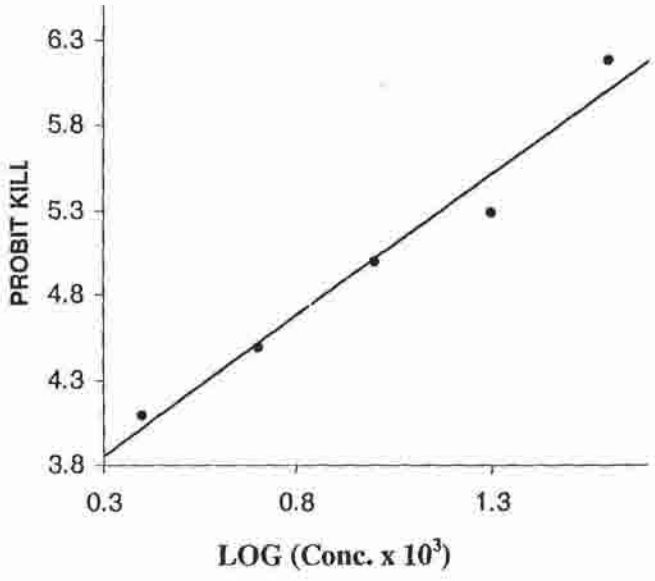
LC_{50}=0.00961 per cent Fiducial limits of LC_{50} = 0.00731-0.01239 per cent

The log (concentration) – probit mortality regression lines are presented in Fig. 4.2.1.

Data (Table 4.2.1) showed that malathion at 0.05 and 0.1 per cent concentrations resulted into 55.56 and 68.89 per cent mortality; endosulfan at 0.05 per cent concentrations resulted into 62.78 per cent and fenvalerate at 0.01 and 0.02 per cent concentrations resulted into 51.22 and 63.42 per cent mortality of 3rd instar larvae, respectively. Hence, to have a selection pressure of 60-80 per cent kill, 0.075, 0.05 and 0.015 per cent concentrations of malathion , endosulfan and fenvalerate were choosen and applied to larvae of the malathion selected (MS)-, endosulfan selected (ES)- and fenvalerate selected (FS)-lines, respectively in the parental generation. Details are as follow:

The MS Line	The ES line	The FS Line
Conc. applied (%) = 0.075	Conc. applied (%) = 0.05	Conc. applied (%) = 0.015
No. of larvae treated =200	No. of larvae treated =300	No. of larvae treated =200
No. of larvae dead = 132	No. of larvae dead = 195	No. of larvae dead = 122
Per cent mortality = 66.00	Per cent mortality = 65.00	Per cent mortality = 61.00





FS- Line

Fig. 4.2.1 Log (conc.) – probit mortality regression lines for malathion, endosulfan and fenvalerate to larvae of *P. xylostella* of the MS-, ES- and FS- lines in parental population

Table: 4.2.2 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_1

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0125	23.33	17.85	0.0125	22.22	20.45
0.025	33.33	28.57	0.025	33.33	31.82
0.05	53.33	50.00	0.05	60.00	59.09
0.1	63.33	60.71	0.1	73.33	72.72
0.2	90.00	85.29	0.2	91.11	90.90
Control	6.67		Control	2.22	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 1.127 (Not heterogeneous at P=0.05) Slope (b) = 1.605 $\pm$ 0.282
Regression equation: y = 1.605 X + 2.241

LC_{50}=0.052 per cent Fiducial limits of LC_{50} = 0.038-0.072 per cent
NS-Line
χ^2 (3) = 0.943 (Not heterogeneous at P=0.05) Slope (b) = 1.777 $\pm$ 0.237
Regression equation: y = 1.777 X + 2.454
LC_{50}=0.041 per cent Fiducial limits of LC_{50} = 0.032-0.052 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.2.

Data (Table 4.2.2) showed that there was 60.71 per cent mortality of 3rd instar larvae of MS-Line in G_1 at 0.1 per cent concentration of malathion. Hence 0.1 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.10
No. of larvae treated =200
No. of larvae dead = 125
Per cent mortality = 62.50

Table: 4.2.3 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_2

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent Corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	23.00	23.00	0.0125	22.22	22.22
0.05	40.00	40.00	0.025	37.78	37.78
0.1	56.67	56.67	0.05	51.11	51.11
0.2	76.67	76.67	0.1	68.89	68.89
0.4	93.33	93.33	0.2	93.33	93.33
Control	0.00		Control	0.00	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 0.548 (Not heterogeneous at P=0.05) Slope (b) = 1.765 $\pm$ 0.289
Regression equation: y = 1.765 X + 1.731
LC_{50}=0.071 per cent Fiducial limits of LC_{50} = 0.053-0.096 per cent

NS-Line
χ^2 (3) = 1.199 (Not heterogeneous at P=0.05) Slope (b) = 1.633 $\pm$ 0.217
Regression equation: y = 1.633x + 2.401
LC_{50}=0.039 per cent Fiducial limits of LC_{50} = 0.032-0.053 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.3.

Data (Table 4.2.3) showed that malathion at 0.1 and 0.2 per cent concentrations resulted into 56.67 and 76.67 per cent mortality of 3rd instar larvae of MS-Line in G_2, respectively. Hence, 0.15 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.15
No. of larvae treated =200
No. of larvae dead = 140
Per cent mortality = 70.00

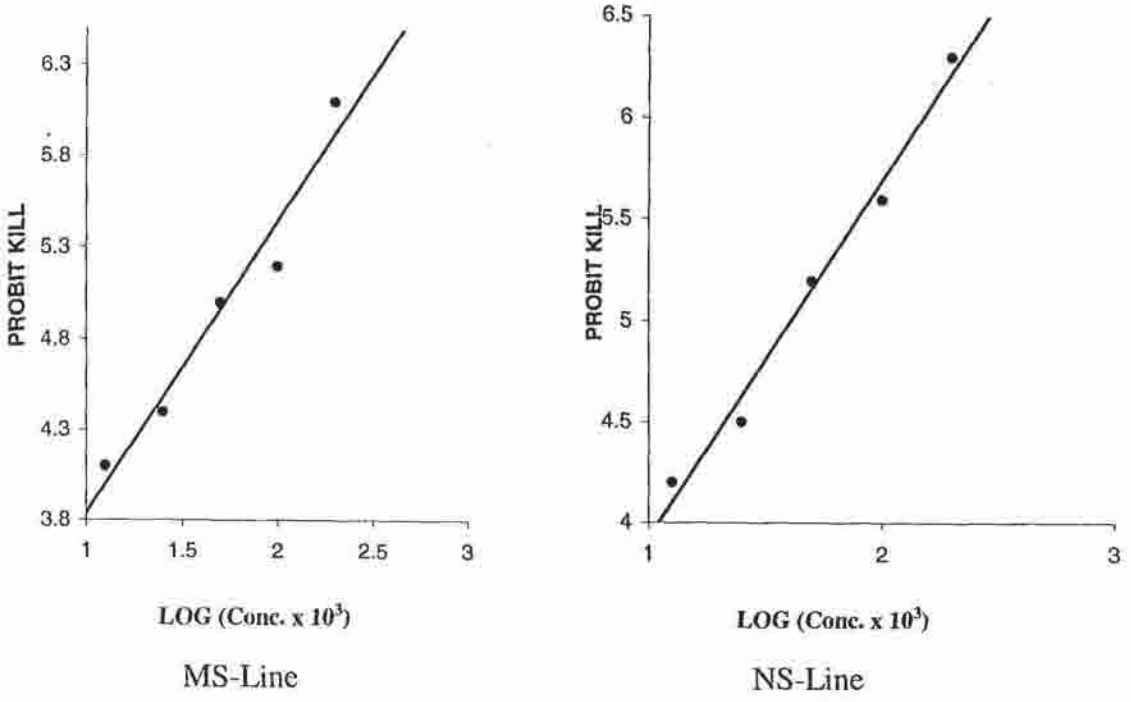


Fig. 4.2.2 Log (conc.) – probit mortality regression lines for malathion to larvae of *P. xylostella* of the MS- and the NS- line in G_1

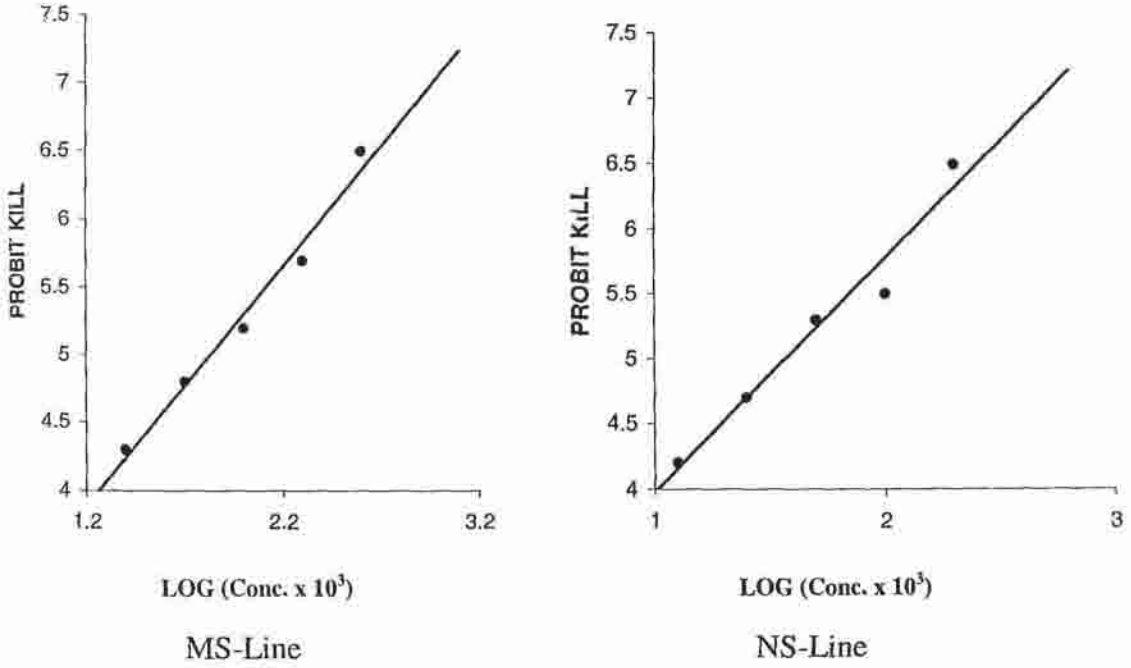


Fig. 4.2.3 Log (conc.) – probit mortality regression lines for malathion to larvae of *P. xylostella* of the MS- and the NS- line in G_2

Table: 4.2.4 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_3

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	24.44	20.93	0.0125	20.00	20.00
0.05	42.22	39.54	0.025	35.56	35.56
0.1	55.56	53.50	0.05	53.33	53.33
0.2	68.89	67.44	0.1	71.11	71..11
0.4	86.67	86.05	0.2	91.11	91.11
Control	4.44		Control	0.00	

Results obtained from probit analysis:
MS-Line
χ^2 (3) =0.339 (Not heterogeneous at P=0.05) Slope (b) = 1.472 $\pm$ 0.
Regression equation: y = 1.471x + 2.165
LC_{50}=0.087 per cent Fiducial limits of LC_{50} = 0.060-0.118 per cent

NS-Line
χ^2 (3) =0.621 (Not heterogeneous at P=0.05) Slope (b) = 1.710 $\pm$ 0.226
Regression equation: y = 1.710x + 2.228
LC_{50}= 0.042 per cent Fiducial limits of LC_{50} = 0.033-0.053 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.4.

Data (Table 4.2.4) showed that malathion at 0.2 per cent concentration resulted into 67.44 per cent mortality of 3rd instar larvae of MS-Line in G_3. Hence 0.2 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.20
No. of larvae treated = 150
No. of larvae dead = 108
Per cent mortality = 72.00

Table: 4.2.5 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_4

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	20.00	16.28	0.0125	23.33	17.86
0.05	40.00	37.21	0.025	50.00	46.43
0.1	51.11	48.84	0.05	60.00	57.15
0.2	64.44	62.07	0.1	66.67	64.29
0.4	80.00	79.07	0.2	86.67	85.72
Control	4.44		Control	6.66	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 0.561 (Not heterogeneous at P=0.05) Slope (b) = 1.366$\pm$ 0.270
Regression equation: y = 1.366 X + 2.214
LC_{50}=0.109 per cent Fiducial limits of LC_{50} = 0.076-0.157 per cent

NS-Line
χ^2 (3) = 3.267 (Not heterogeneous at P=0.05) Slope (b) = 1.430 $\pm$ 0.220
Regression equation: y = 1.430X + 2.740
LC_{50}=0.040 per cent Fiducial limits of LC_{50} = 0.031-0.055 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.5.

Data (Table 4.2.5) showed that there was 62.07 per cent mortality of 3rd instar larvae of MS-Line in G_4 at 0.2 per cent concentration of malathion. Hence 0.2 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.20
No. of larvae treated =150
No. of larvae dead = 98
Per cent mortality = 65.33

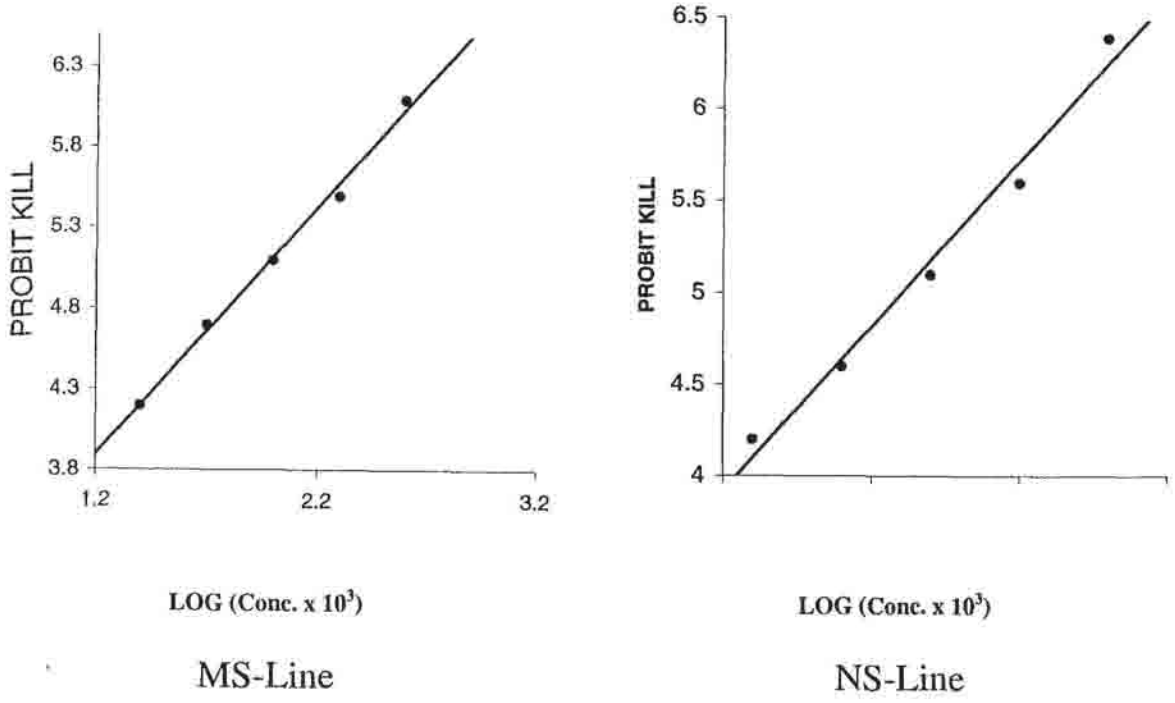


Fig. 4.2.4 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_3

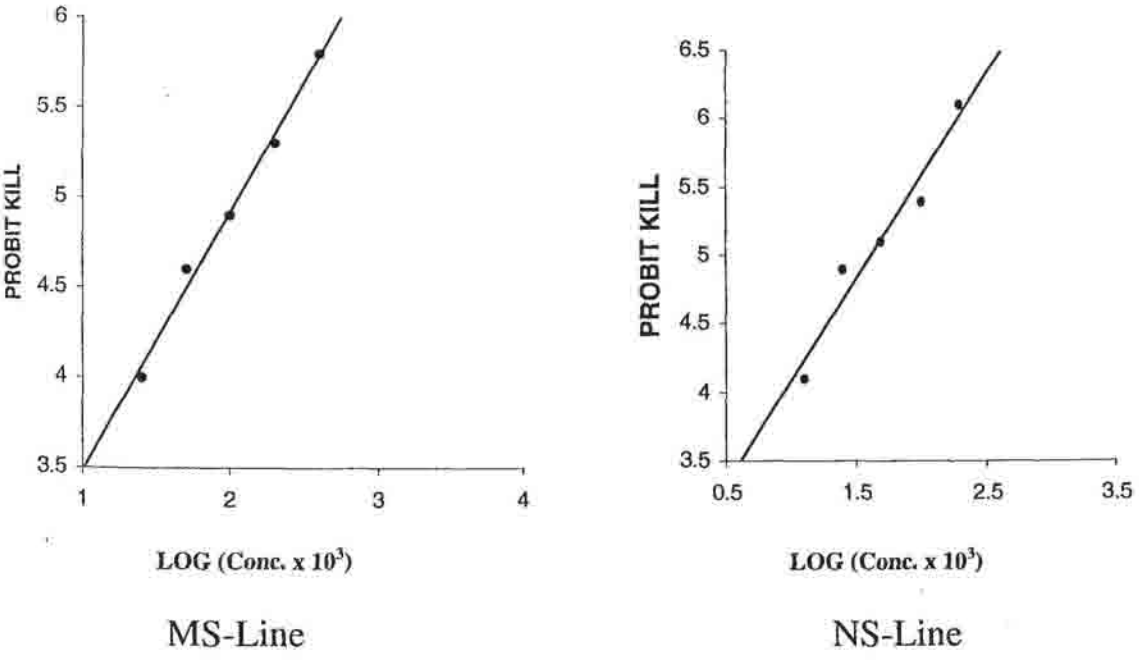


Fig. 4.2.5 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_4

Table: 4.2.6 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_5

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.05	20.00	17.24	0.0125	26.67	21.44
0.1	40.00	37.93	0.025	40.00	35.72
0.2	53.33	51.72	0.05	60.00	57.15
0.4	76.67	75.87	0.1	77.78	76.19
0.6	90.00	89.66	0.2	91.11	90.48
Control	3.33		Control	6.66	

Results obtained from probit analysis:

MS-Line

χ^2 (3) = 0.815 (Not heterogeneous at P=0.05) Slope (b) = 1.898 $\pm$ 0.313

Regression equation: y = 1.898 X +0.818

LC_{50}= 0.159 per cent Fiducial limits of LC_{50} = 0.121-0.210 per cent

NS-Line

χ^2 (3) = 5.133 (Not heterogeneous at P=0.05) Slope (b) = 1.749 $\pm$ 0.239

Regression equation: y = 1.749 X + 2.228

LC_{50}= 0.038 per cent Fiducial limits of LC_{50} = 0.030-0.049 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.6.

Data (Table 4.2.6) showed that malathion at 0.2 and 0.4 per cent concentration resulted into 51.72 and 75.87 per cent per cent mortality of 3rd instar larvae of MS-Line in G_5. Hence 0.30 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 0.30

No. of larvae treated =150

No. of larvae dead = 95

Per cent mortality = 63.33

Table: 4.2.7 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_6

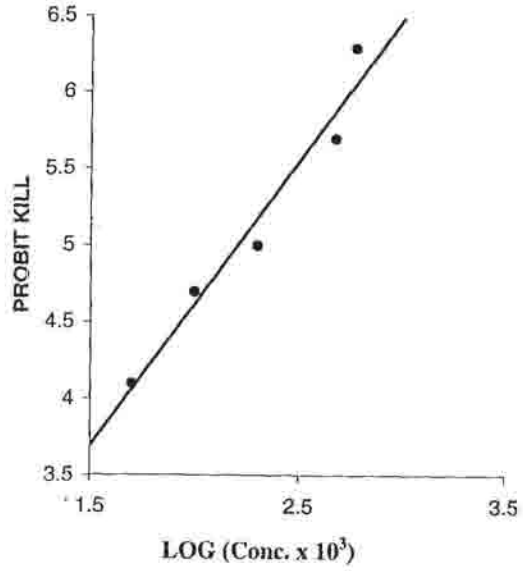
MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.05	16.67	16.67	0.0125	26.66	23.25
0.1	36.67	36.67	0.025	35.56	32.55
0.2	50.00	50.00	0.05	62.22	60.46
0.4	73.33	73.33	0.1	71.11	69.76
0.6	83.33	83.33	0.2	86.67	86.04
Control	0.00		Control	4.44	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 0.144 (Not heterogeneous at P=0.05) Slope (b) = 1.773 $\pm$ 0.229
Regression equation: y = 1.773X + 1.000
LC_{50}=0.179 Fiducial limits of LC_{50} = 0.136-0.239 per cent

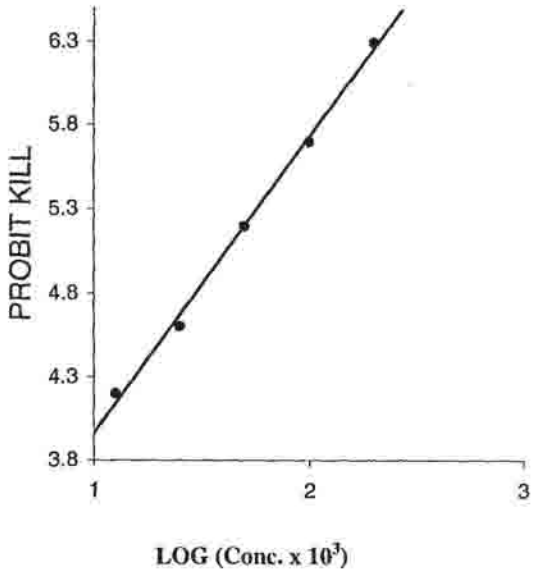
NS-Line
χ^2 (3) = 1.220 (Not heterogeneous at P=0.05) Slope (b) = 1.515 $\pm$ 0.223
Regression equation: y = 1.515 X + 2.612
LC_{50}=0.037 per cent Fiducial limits of LC_{50} = 0.039-0.054 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.7.

Data (Table 4.2.7) showed that there was 50.00 and 73.33 per cent mortality at 0.2 and 0.4 per cent concentration of 3rd instar larvae of MS-Line in G_6. Hence 0.35 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.35
No. of larvae treated =200
No. of larvae dead = 131
Per cent mortality = 65.50

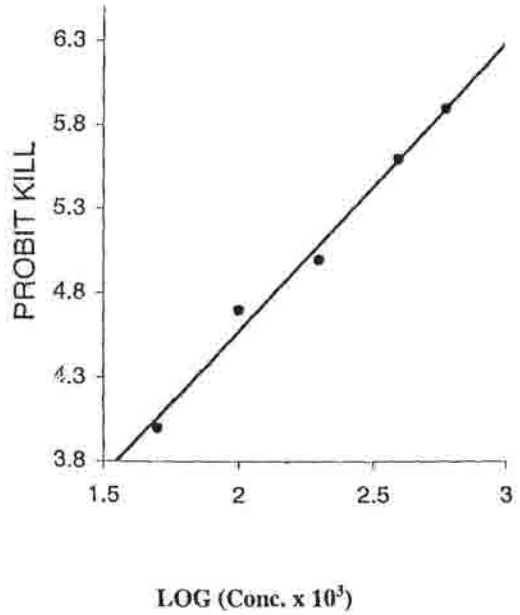


MS-Line

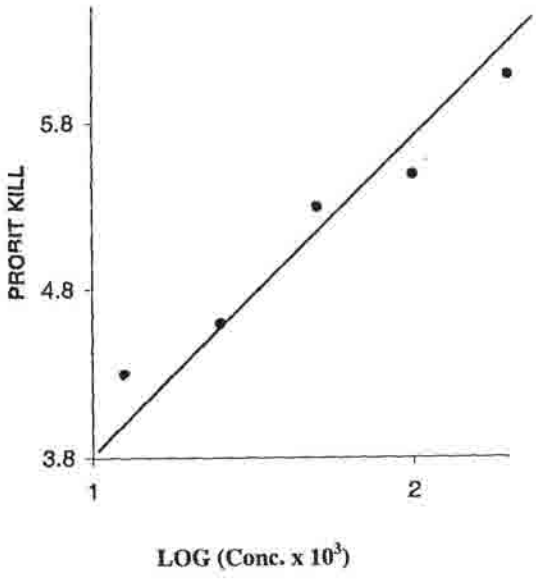


NS-Line

Fig. 4.2.6 Log (conc.) – probit mortality regression lines for malathion to larvae of *P. xylostella* of the MS- and the NS- line in G_5



MS-Line



NS-Line

Fig. 4.2.7 Log (conc.) – probit mortality regression lines for malathion to larvae of *P. xylostella* of the MS- and the NS- line in G_6

Table: 4.2.8 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_7

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.1	26.67	24.14	0.0125	28.89	25.59
0.2	43.33	41.38	0.025	40.00	37.21
0.4	66.67	65.52	0.05	62.22	60.46
0.6	76.67	75.87	0.1	66.67	65.12
0.8	93.33	93.10	0.2	93.33	93.02
Control	3.33		Control	4.44	

Results obtained from probit analysis:

MS-Line

χ^2 (3) = 1.548 (Not heterogeneous at P=0.05) Slope (b) = 2.121 $\pm$ 0.354

Regression equation: y = 2.121 X + 0.354

LC_{50}=0.238 per cent Fiducial limits of LC_{50} =0.184-0.306 per cent

NS-Line

χ^2 (3) = 3.415 (Not heterogeneous at P=0.05) Slope (b) = 1.548 $\pm$ 0.224

Regression equation: y = 1.548 X + 2.563

LC_{50}=0.038 per cent Fiducial limits of LC_{50} = 0.029-0.049 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.8.

Data (Table 4.2.8) showed that there was 65.52 per cent mortality of 3rd instar larvae of MS-Line in G_7 at 0.4 per cent concentration of malathion. Hence 0.4 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:

Conc. applied (%) = 0.40

No. of larvae treated =200

No. of larvae dead = 142

Per cent mortality = 71.00

Table: 4.2.9 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_8

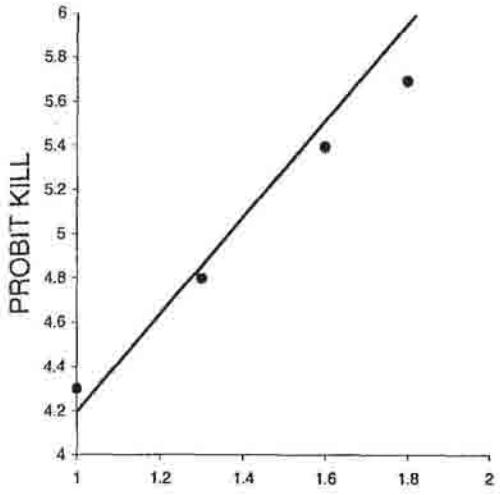
MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.1	23.33	17.85	0.0125	20.00	20.00
0.2	40.00	35.71	0.025	46.67	46.67
0.4	56.67	53.57	0.05	57.78	57.78
0.6	70.00	67.86	0.1	66.67	66.67
0.8	83.33	82.14	0.2	86.67	86.67
Control	6.67	0.00	Control	0.00	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 0.581 (Not heterogeneous at P=0.05) Slope (b) = 1.920 $\pm$ 0.353
Regression equation: y = 1.920X + 2.116
LC_{50}=0.318 per cent Fiducial limits of LC_{50} = 0.245-0.411 per cent

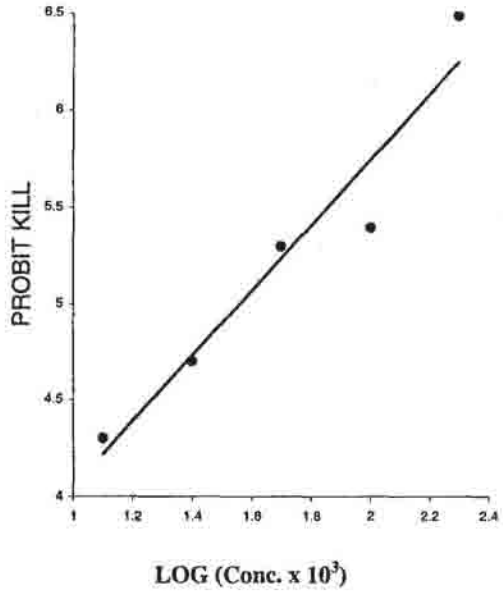
NS-Line
χ^2 (3) = 2.265 (Not heterogeneous at P=0.05) Slope (b) = 1.434 $\pm$ 0.223
Regression equation: y = 1.434 X + 2.726
LC_{50}=0.039 per cent Fiducial limits of LC_{50} = 0.029-0.051 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.9.

Data (Table 4.2.9) showed that there was 53.57 and 67.86 per cent mortality at 0.4 and 0.6 per cent of 3rd instar larvae of MS-Line in G at 0.6 per cent concentration of malathion. Hence 0.6 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.60
No. of larvae treated =200
No. of larvae dead = 128
Per cent mortality = 64.00

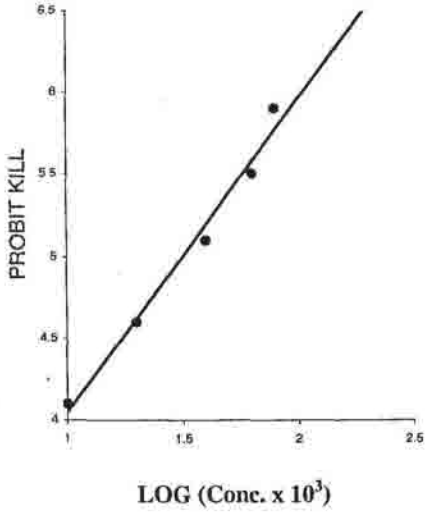


MS-Line

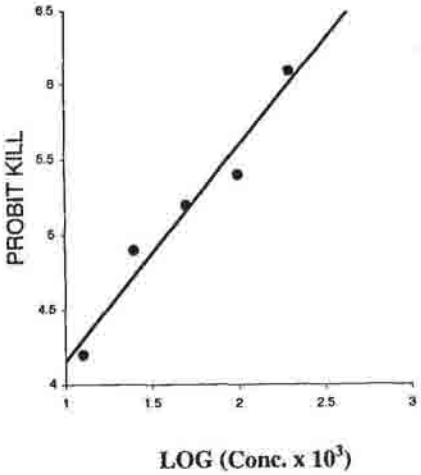


NS-Line

Fig. 4.2.8 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_7



MS-Line



NS-Line

Fig. 4.2. 9 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_8

Table: 4.2.10 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_9

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.2	23.33	23.33	0.0625	20.00	14.28
0.4	43.33	43.33	0.0125	26.67	21.43
0.6	56.67	56.67	0.025	40.00	35.71
0.8	70.00	70.00	0.05	62.22	59.51
1.0	86.67	86.67	0.1	75.56	73.81
Control	0.00		Control	6.67	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 6.172 (Not heterogeneous at P=0.05) Slope (b) = 2.251$\pm$ 0447
Regression equation: y = 2.251 X + 1.194
LC_{50}=0.491 per cent Fiducial limits of LC_{50} = 0.395-0.608 per cent

NS-Line
χ^2 (3) = 0.698 (Not heterogeneous at P=0.05) Slope (b) = 1.498 $\pm$ 0.228
Regression equation: y = 1.498 X + 2.629
LC_{50}=0.038 per cent Fiducial limits of LC_{50} = 0.029-0.051 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.10.

Data (Table 4.2.10) showed that there was 56.67 and 70.00 per cent mortality at 0.6 and 0.8 per cent of 3rd instar larvae of MS-Line in G_9 of malathion. Hence 0.65 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.65
No. of larvae treated =250
No. of larvae dead = 152
Per cent mortality = 60.80

Table: 4.2.11 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_{10}

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.2	16.67	16.67	0.0125	31.11	26.18
0.4	36.67	36.67	0.025	46.67	42.85
0.6	53.33	53.33	0.05	68.89	66.66
0.8	63.33	63.33	0.1	75.56	73.81
1.0	80.00	80.00	0.2	95.56	95.23
Control	0.00		Control	6.67	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 0.678 (Not heterogeneous at P=0.05) Slope (b) = 2.453 $\pm$ 0.481
Regression equation: y = 2.453 X + 0.766
LC_{50}=0.532 per cent Fiducial limits of LC_{50} = 0.435-0.650 per cent

NS-Line
χ^2 (3) = 2.188 (Not heterogeneous at P=0.05) Slope (b) = 1.701 $\pm$ 0.237
Regression equation: y = 1.701 X + 2.403
LC_{50}=0.034 per cent Fiducial limits of LC_{50} = 0.026-0.044 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.11.

Data (Table 4.2.11) showed that malathion at a concentration of 0.8 per cent resulted into 63.33 per cent mortality of 3rd instar larvae of the MS- line in G_{10}. Hence 0.8 per cent concentration of malathion was choosen to cause a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 0.80
No. of larvae treated =250
No. of larvae dead = 170
Per cent mortality = 68.00

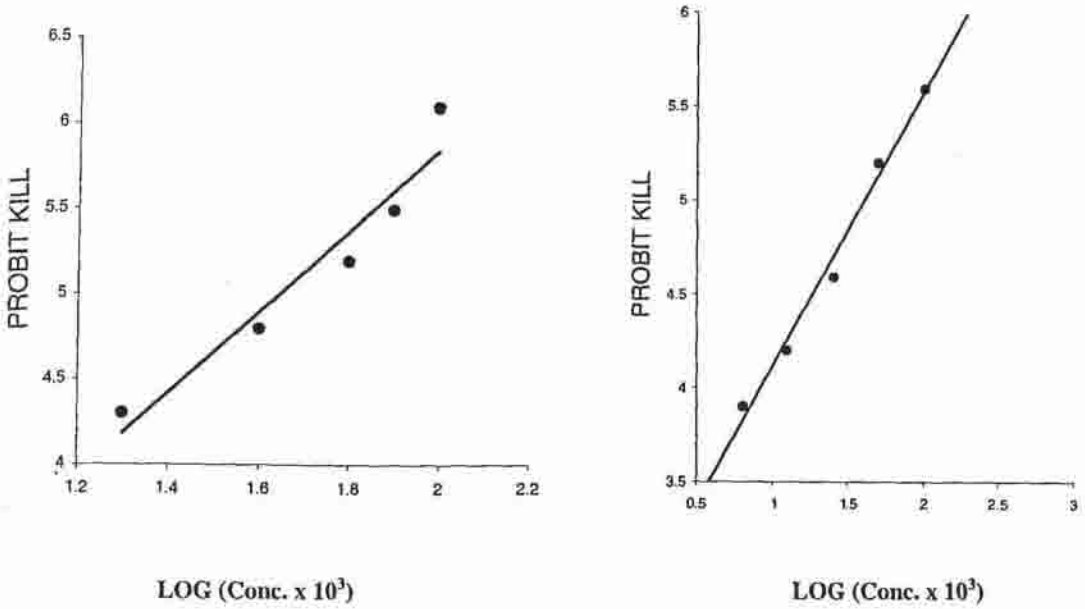


Fig. 4.2.10 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_9

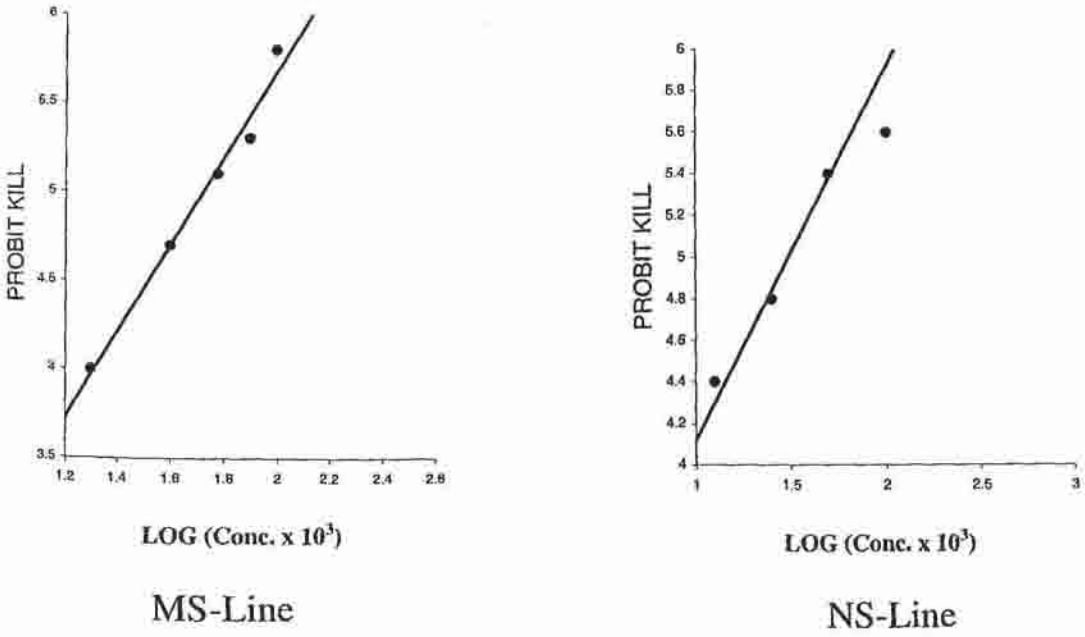


Fig. 4.2.11 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_{10}

Table: 4.2.12 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_{11}

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.2	13.33	10.34	0.00625	17.78	13.96
0.4	23.33	20.69	0.0125	24.44	20.93
0.6	43.33	41.37	0.025	42.22	39.54
0.8	53.33	51.72	0.05	60.00	58.14
1.0	76.67	75.87	0.1	77.78	76.75
2.0	90.00	89.66	Control	4.44	
Control	3.33				

Results obtained from probit analysis:
MS-Line
χ^2 (4) = 2.186 (Not heterogeneous at P=0.05) Slope (b) = 2.713 $\pm$ 0.402
Regression equation: y = 2.713 X + 0.024
LC_{50}=0.685 per cent Fiducial limits of LC_{50} = 0.574-0.819 per cent

NS-Line
χ^2 (3) = 0.526 (Not heterogeneous at P=0.05) Slope (b) = 1.549 $\pm$ 0.234
Regression equation: y = 1.549 X + 2.584
LC_{50}=0.036 per cent Fiducial limits of LC_{50} = 0.028-0.048 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.12.

Data (Table 4.2.12) showed that there was 75.87 per cent mortality at 1.00 per cent of 3rd instar larvae of MS-Line in G_{11} of malathion. Hence 1.00 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 1.00
No. of larvae treated =250
No. of larvae dead = 158
Per cent mortality = 63.20

Table: 4.2.13 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_{12}

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.4	20.00	17.24	0.0125	23.33	20.69
0.6	40.00	37.93	0.025	36.67	34.49
0.8	50.00	48.28	0.05	60.00	58.62
1.0	73.33	72.41	0.1	76.67	75.87
2.0	86.67	86.21	0.2	93.33	93.10
Control	3.33		Control	3.33	

Results obtained from probit analysis:

MS-Line

χ^2 (3) =2.375 (Not heterogeneous at P=0.05) Slope (b) = 3.001 $\pm$ 0.449

Regression equation: y = 3.001 X - 0.655

LC_{50}=0.776 per cent Fiducial limits of LC_{50} = 0.667-0.880 per cent

NS-Line

χ^2 (3) = 0.649 (Not heterogeneous at P=0.05) Slope (b) = 1.863 $\pm$ 0.236

Regression equation: y = 1.862 X + 2.925

LC_{50}=0.035 per cent Fiducial limits of LC_{50} = 0.028-0.049 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.13.

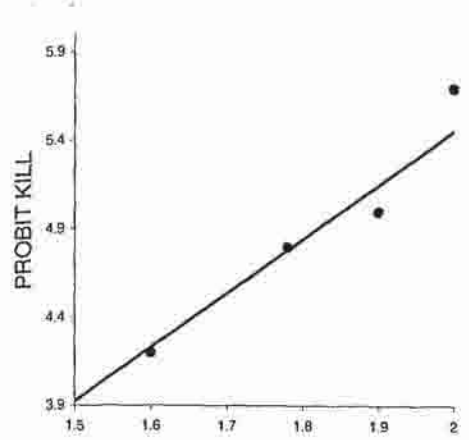
Data (Table 4.2.13) showed that malathion at 1.00 and per cent concentration resulted into 72.41 per cent per cent mortality of 3rd instar larvae of MS-Line in G_{12}. Hence 1.00 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 1.00

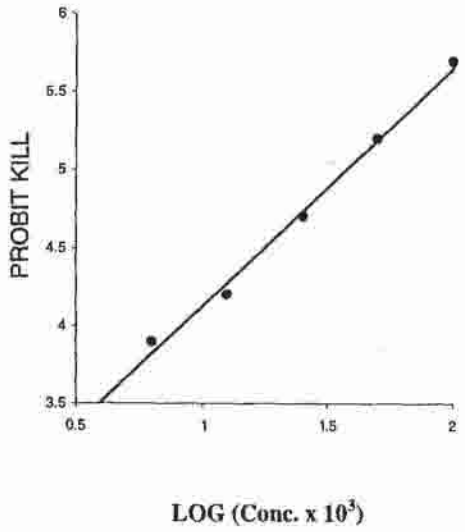
No. of larvae treated =250

No. of larvae dead = 168

Per cent mortality = 67.20

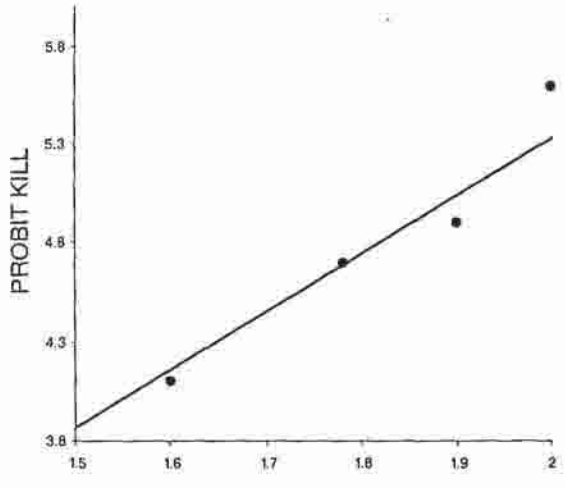


MS-Line

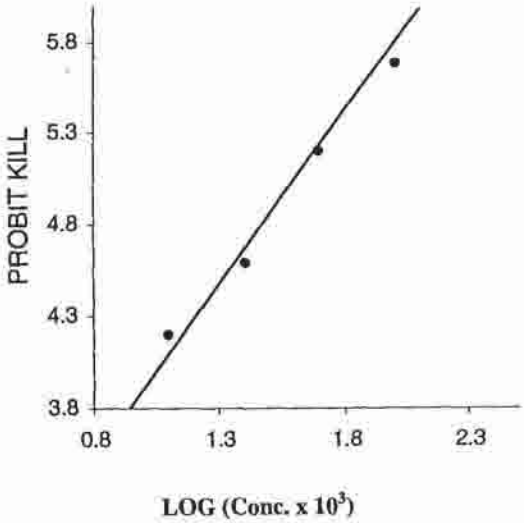


NS-Line

Fig. 4.2.12 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_{11}



MS-Line



NS-Line

Fig. 4.2.13 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_{12}

Table: 4.1.14 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_{13}

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.6	20.00	14.28	0.0125	30.00	27.59
0.8	36.67	32.14	0.025	40.00	37.93
1.0	50.00	46.43	0.05	60.00	58.62
2.0	73.33	71.42	0.1	80.00	79.31
4.0	86.67	85.72	0.2	93.33	93.10
Control	6.67		Control	3.33	

Results obtained from probit analysis:
MS-Line
χ^2 (3) = 3.981 (Not heterogeneous at P=0.05) Slope (b) = 3.169 $\pm$ 0.445
Regression equation: y = 3.169 X - 1.057
LC_{50}=0.814 per cent Fiducial limits of LC_{50} = 0.714-0.928 per cent

NS-Line
χ^2 (3) = 1.246 (Not heterogeneous at P=0.05) Slope (b) = 1.689 $\pm$ 0.245
Regression equation: y = 1.689 X + 2.431
LC_{50}=0.033 per cent Fiducial limits of LC_{50} = 0.026-0.043 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.14.

Data (Table 4.2.6) showed that malathion at 1.0 and 2.0 per cent concentration resulted into 46.43 and 71.42 per cent per cent mortality of 3rd instar larvae of MS-Line in G_{13}. Hence 1.15 per cent concentration of malathion was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 1.15
No. of larvae treated =250
No. of larvae dead = 187
Per cent mortality = 74.80

Table: 4.2.15 Toxicity of malathion to larvae of MS- and NS- lines of *P. xylostella* in G_{14}

MS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.3	13.33	13.33	0.00625	26.66	23.25
0.6	26.67	26.67	0.0125	44.44	41.86
0.8	43.33	43.33	0.025	71.11	69.77
1.0	66.67	66.67	0.05	82.22	81.39
2.0	83.33	83.33	0.1	91.00	90.58
Control	0.00		Control	4.44	

Results obtained from probit analysis:

MS-Line

χ^2 (3) = 3.471 (Not heterogeneous at P=0.05) Slope (b) = 2.682 $\pm$ 0.0.398

Regression equation: y = 2.682 X – 0.169

LC_{50}=0.847 per cent Fiducial limits of LC_{50} = 0.734-0.990 per cent

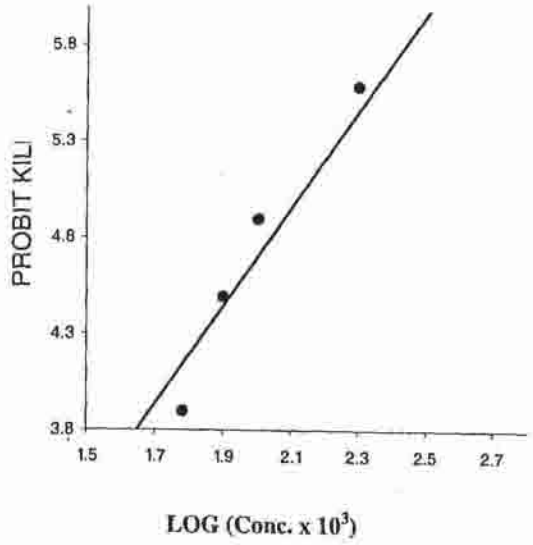
NS-Line

χ^2 (3) = 0.788 (Not heterogeneous at P=0.05) Slope (b) = 1.754 $\pm$ 0.235

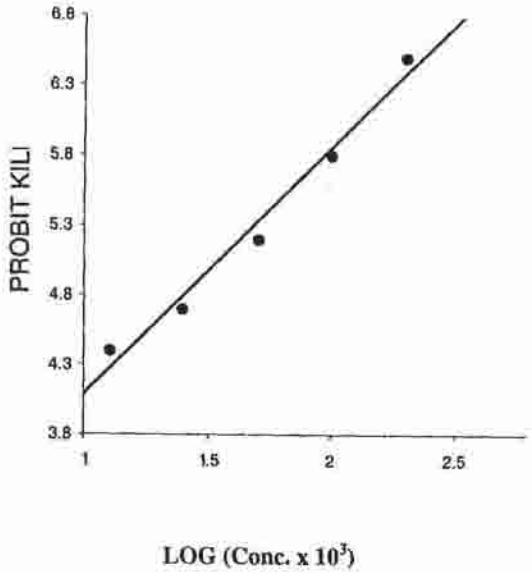
Regression equation: y = 1.754 X + 2.382

LC_{50}=0.031 Fiducial limits of LC_{50} = 0.024-0.040 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.15.

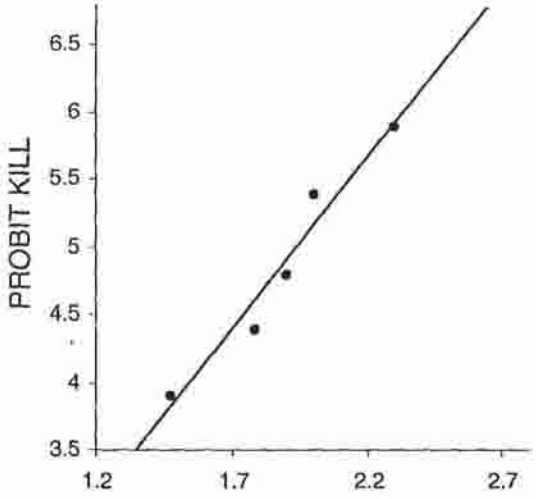


MS-Line

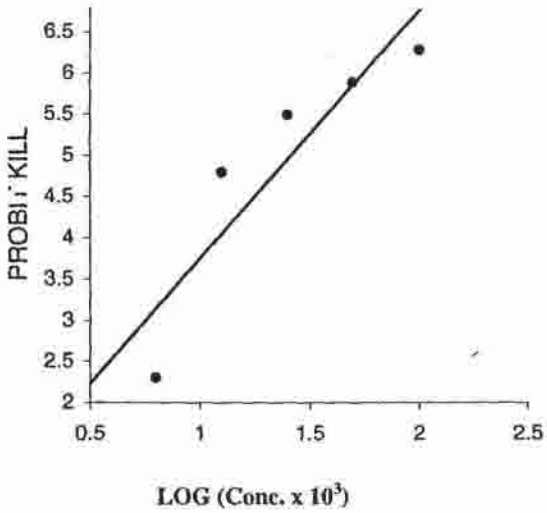


NS-Line

Fig. 4.2.14 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_{13}



MS-Line



NS-Line

Fig. 4.2.15 Log (conc.) – probit mortality regression lines for malathion to the larvae of *P. xylostella* of the MS- and the NS- line in G_{14}

Table: 4.2.16 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_1

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.00625	17.78	13.96	0.00625	22.22	16.67
0.0125	31.11	27.91	0.0125	35.56	30.95
0.025	42.22	39.54	0.025	51.11	47.62
0.05	57.78	55.82	0.05	64.44	61.90
0.1	71.11	69.77	0.1	71.11	69.05
0.2	84.44	83.72	Control	6.67	
Control	4.44				

Results obtained from probit analysis:

ES-Line

χ^2 (4) = 0.179 (Not heterogeneous at P=0.05) Slope (b) = 1.321 $\pm$ 0.170

Regression equation: y = 1.321 X + 2.904

LC_{50}=0.039 per cent Fiducial limits of LC_{50} = 0.029-0.051 per cent

NS-Line

χ^2 (3) = 0.838 (Not heterogeneous at P=0.05) Slope (b) = 1.202 $\pm$ 0.227

Regression equation: y = 1.202 X + 3.179

LC_{50}=0.033 per cent Fiducial limits of LC_{50} = 0.024-0.045 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.16.

Data (Table 4.2.16) showed that endosulfan at 0.1 and 0.2 per cent concentration resulted into 69.77 and 83.72 per cent per cent mortality of 3rd instar larvae of ES-Line in G_1. Hence 1.15 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 0.075

No. of larvae treated =300

No. of larvae dead = 214

Per cent mortality = 71.33

Table: 4.2.17 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_2

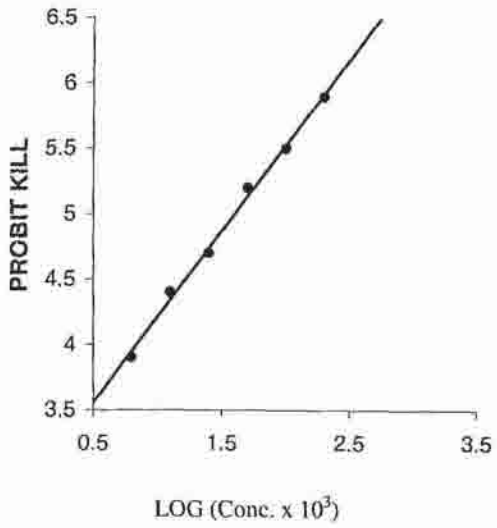
ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0125	11.11	9.09	0.00625	20.00	16.28
0.025	22.22	20.45	0.0125	37.87	34.89
0.05	44.44	43.18	0.025	46.67	44.19
0.1	66.67	65.91	0.05	62.22	60.46
0.2	76.67	76.14	0.1	75.56	74.42
0.4	93.33	93.18	0.2	86.67	86.05
Control	2.22		Control	4.44	

Results obtained from probit analysis:
ES-Line
χ^2 (4) = 1.033 (Not heterogeneous at P=0.05) Slope (b) = 1.821 $\pm$ 0.197
Regression equation: y = 1.821 X + 1.679
LC_{50}=0.068 per cent Fiducial limits of LC_{50} = 0.054-0.083 per cent

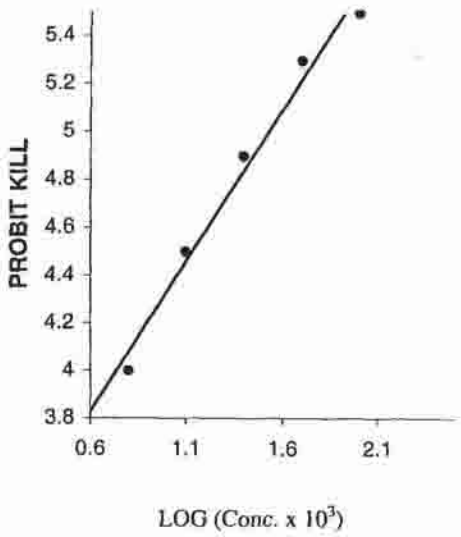
NS-Line
χ^2 (4) = 0.642 (Not heterogeneous at P=0.05) Slope (b) = 1.301 $\pm$ 0.170
Regression equation: y = 1.301 X + 3.065
LC_{50}=0.031 per cent Fiducial limits of LC_{50} = 0.023-0.041 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.17.

Data (Table 4.2.17) showed that endosulfan at 0.1 and 0.2 per cent concentration resulted into 65.91 and 76.14 per cent per cent mortality of 3rd instar larvae of ES-Line in G_2. Hence 1.15 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.10
No. of larvae treated =300
No. of larvae dead = 198
Per cent mortality = 66.00

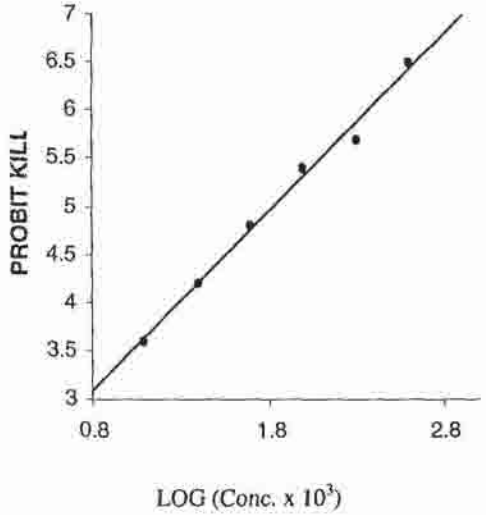


ES-Line

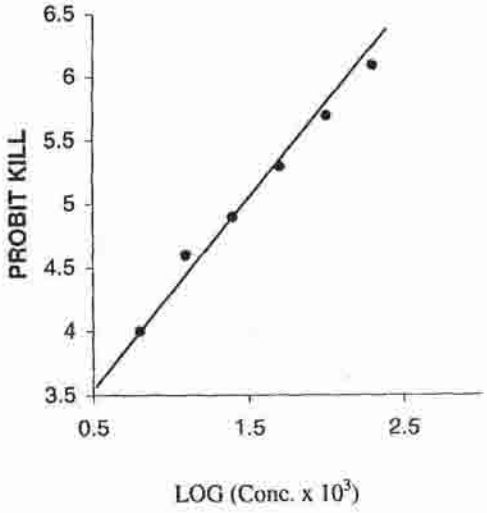


NS-Line

Fig. 4.2.16 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_1



ES-Line



NS-Line

Fig. 4.2.17 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_2

Table: 4.2.18 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_3

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	20.00	16.28	0.00625	20.00	18.18
0.05	44.44	41.86	0.0125	33.33	31.82
0.1	64.44	62.79	0.025	51.11	50.00
0.2	71.11	69.77	0.05	62.22	61.36
0.4	91.11	90.69	0.1	71.11	70.45
Control	4.44		Control	2.22	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 2.400 (Not heterogeneous at P=0.05) Slope (b) = 1.729 $\pm$ 0.237
Regression equation: y = 1.729 X + 1.739
LC_{50}=0.077 per cent Fiducial limits of LC_{50} = 0.059-0.099 per cent
NS-Line
χ^2 (3) = 0.066 (Not heterogeneous at P=0.05) Slope (b) = 1.202 $\pm$ 0.214
Regression equation: y = 1.202 X + 3.197
LC_{50}=0.032 per cent Fiducial limits of LC_{50} = 0.022-0.043 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.18.

Data (Table 4.2.118) showed that there was 62.79 and 69.77 per cent mortality at 0.1 and 0.2 per cent of 3rd instar larvae of ES-Line in G_3 of endosulfan. Hence 1.00 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.15
No. of larvae treated =300
No. of larvae dead = 192
Per cent mortality = 64.00

Table: 4.2.19 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_4

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	13.33	13.33	0.00625	17.78	13.96
0.05	35.56	35.56	0.0125	37.78	34.89
0.1	55.56	55.56	0.025	53.33	51.16
0.2	66.67	66.67	0.05	62.22	60.46
0.4	86.67	86.67	0.1	75.56	74.42
Control	0.00		0.2	84.44	83.72
			Control	4.44	

Results obtained from probit analysis:

ES-Line
χ^2 (3) = 1.302 (Not heterogeneous at P=0.05) Slope (b) = 1.696 $\pm$ 0.230
Regression equation: y = 1.696 X + 1.654
LC_{50}=0.094 per cent Fiducial limits of LC_{50} = 0.073-0.119 per cent

NS-Line
χ^2 (4) = 1.802 (Not heterogeneous at P=0.05) Slope (b) = 1.278 $\pm$ 0.169
Regression equation: y = 1.278 X + 3.109
LC_{50}=0.030 per cent Fiducial limits of LC_{50} = 0.023-0.041 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.19.

Data (Table 4.2.19) showed that there was 66.67 per cent mortality at 0.2 per cent of 3rd instar larvae of ES-Line in G_{11} of endosulfan. Hence 0.20 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.20
No. of larvae treated =300
No. of larvae dead = 195
Per cent mortality = 65.00

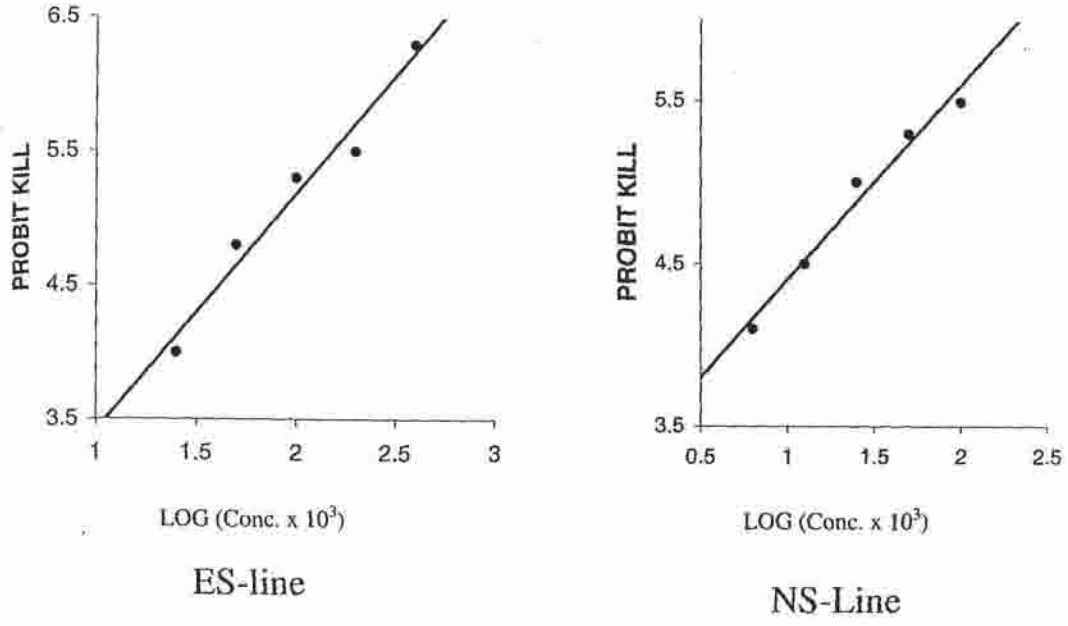


Fig. 4.2.18 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_3

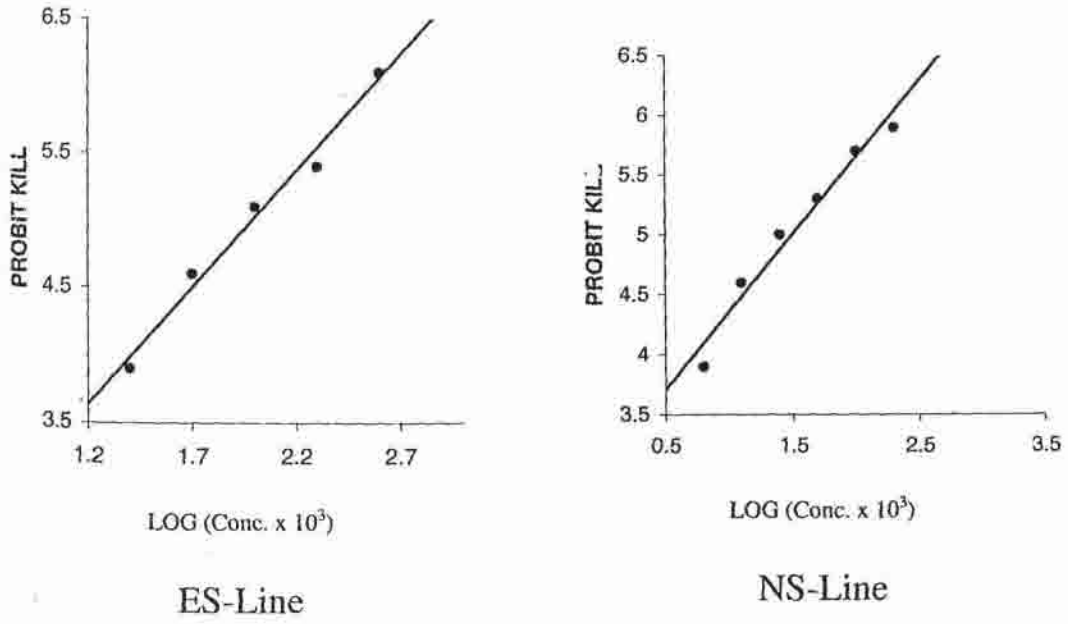


Fig. 4.2.19 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_4

Table: 4.1.20 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_5

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	11.11	9.09	0.00625	17.78	17.78
0.05	24.44	20.45	0.0125	35.56	35.56
0.1	42.22	40.91	0.025	48.89	48.89
0.2	64.44	63.63	0.05	64.44	64.44
0.4	82.22	81.82	0.1	73.33	73.33
Control	2.22		0.2	84.44	84.44
			Control	0.00	

Results obtained from probit analysis:

ES-Line

χ^2 (3) = 0.034 (Not heterogeneous at P=0.05) Slope (b) = 1.889 $\pm$ 0.241

Regression equation: y = 1.889 X + 0.991

LC_{50}=0.132 per cent Fiducial limits of LC_{50} = 0.106-0.166 per cent

NS-Line

χ^2 (4) = 0.654 (Not heterogeneous at P=0.05) Slope (b) = 1.234 $\pm$ 0.169

Regression equation: y = 1.234 X + 3.225

LC_{50}=0.027 per cent Fiducial limits of LC_{50} = 0.021-0.039 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.20.

Data (Table 4.2.16) showed that endosulfan at 0.2 and 0.4 per cent concentration resulted into 63.63 and 81.82 per cent per cent mortality of 3rd instar larvae of ES-Line in G_5. Hence 0.25 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 0.25

No. of larvae treated =300

No. of larvae dead = 216

Per cent mortality = 72.00

Table: 4.2.21 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_6

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.05	17.78	11.90	0.00625	20.00	16.28
0.1	31.11	26.19	0.0125	37.78	34.89
0.2	57.78	54.74	0.025	48.89	46.52
0.4	75.56	73.81	0.05	64.44	62.79
0.6	88.89	88.09	0.1	73.78	72.56
Control	6.67		0.2	91.11	90.70
			Control	4.44	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 0.316 (Not heterogeneous at P=0.05) Slope (b) = 2.109 $\pm$ 0.268
Regression equation: y = 2.109 X + 0.233
LC_{50}=0.182 per cent Fiducial limits of LC_{50} = 0.148-0.225 per cent

NS-Line
χ^2 (4) = 1.171 (Not heterogeneous at P=0.05) Slope (b) = 1.371 $\pm$ 0.169
Regression equation: y = 1.371 X + 2.995
LC_{50}=0.029 per cent Fiducial limits of LC_{50} = 0.022-0.038 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.21.

Data (Table 4.2.21) showed that there was 54.74 and 73.81 per cent mortality at 0.2 and 0.4 per cent of 3rd instar larvae of ES-Line in G_6 of endosulfan. Hence 0.30 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.30
No. of larvae treated =200
No. of larvae dead = 122
Per cent mortality = 61.00

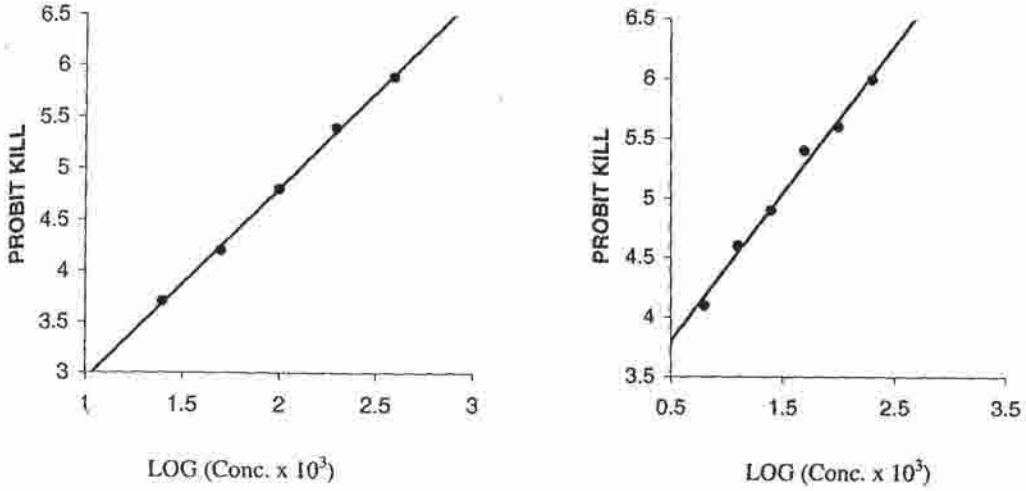


Fig. 4.2.20 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_5

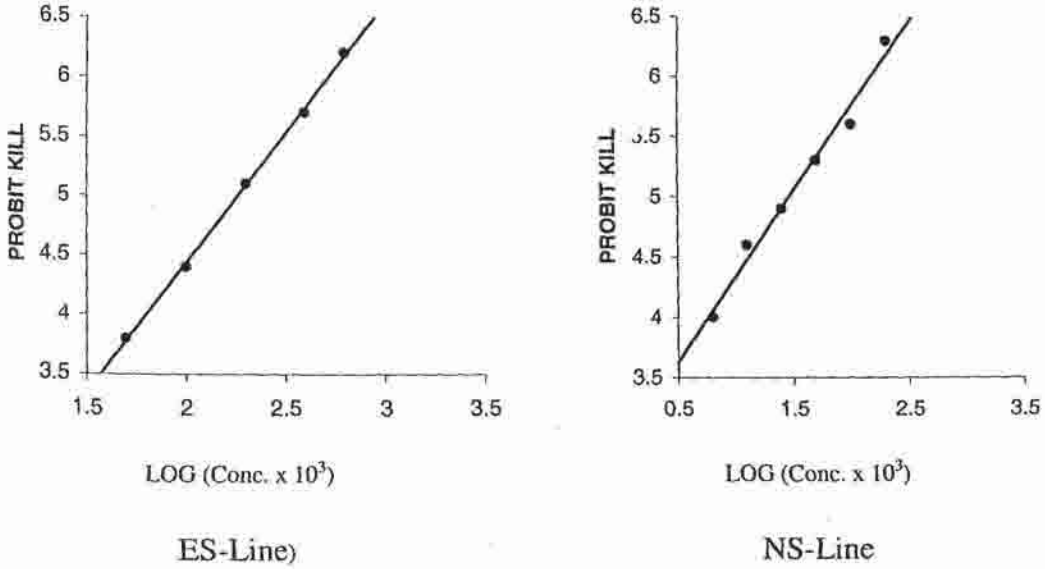


Fig. 4.2.21 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_6

Table: 4.2.22 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_7

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.05	11.11	11.11	0.00625	17.78	13.96
0.1	26.67	26.67	0.0125	35.56	32.57
0.2	46.67	46.67	0.025	53.33	51.16
0.4	57.78	57.78	0.05	66.67	65.12
0.6	80.00	80.00	0.1	75.56	74.42
Control	0.00		Control	4.44	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 1.575 (Not heterogeneous at P=0.05) Slope (b) = 1.739 $\pm$ 0.249
Regression equation: y = 1.739 X + 0.859
LC_{50}=0.240 per cent Fiducial limits of LC_{50} = 0.188-0.305 per cent

NS-Line
χ^2 (3) = 2.359 (Not heterogeneous at P=0.05) Slope (b) = 1.318 $\pm$ 0.221
Regression equation: y = 1.318 X + 3.048
LC_{50}=0.030 per cent Fiducial limits of LC_{50} = 0.022-0.041 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.22.

Data (Table 4.2.22) showed that there was 57.78 per cent mortality at 0.4 per cent of 3rd instar larvae of ES-Line in G_7 of endosulfan. Hence 0.4 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.40
No. of larvae treated =200
No. of larvae dead = 120
Per cent mortality = 60.00

Table: 4.1.23 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_8

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.1	22.22	18.61	0.00625	13.33	13.33
0.2	40.00	37.21	0.0125	33.33	33.33
0.4	51.11	48.84	0.025	51.11	51.11
0.6	77.78	76.75	0.05	64.44	64.44
0.8	88.89	88.37	0.1	73.33	73.33
Control	4.44		Control	0.00	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 4.027 (Not heterogeneous at P=0.05) Slope (b) = 2.147 $\pm$ 0.291
Regression equation: Y = 2.147 X + 1.849
LC_{50}=0.293 per cent Fiducial limits of LC_{50} = 0.241-0.356 per cent

NS-Line
χ^2 (3) = 1.627 (Not heterogeneous at P=0.05) Slope (b) = 1.365 $\pm$ 0.232
Regression equation: Y = 1.365 X + 3.008
LC_{50}=0.029 per cent Fiducial limits of LC_{50} = 0.021-0.039 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.23.

Data (Table 4.2.23) showed that endosulfan at 0.4 and 0.6 per cent concentration resulted into 48.84 and 76.75 per cent per cent mortality of 3rd instar larvae of ES-Line in G_8. Hence 0.50 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.50
No. of larvae treated =200
No. of larvae dead = 130
Per cent mortality = 65.00

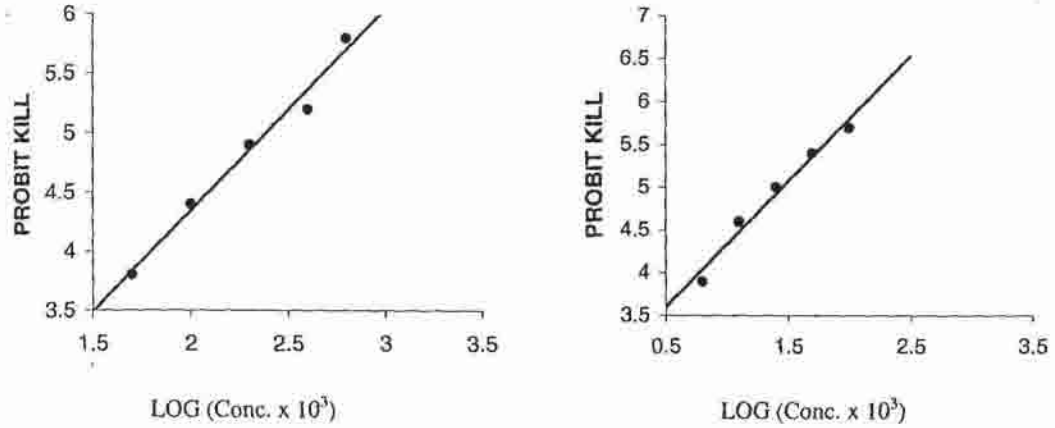


Fig. 4.2.22 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_7

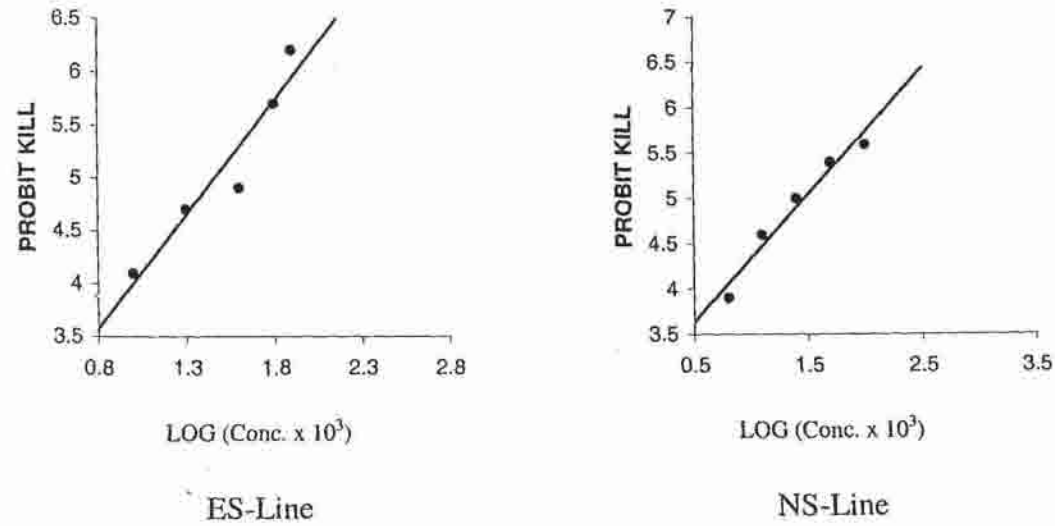


Fig. 4.2.23 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_8

Table: 4.2.24 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_9

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.1	15.56	11.63	0.00625	22.22	20.45
0.2	28.89	25.59	0.0125	40.00	38.64
0.4	44.44	41.86	0.025	51.00	49.89
0.6	64.44	62.79	0.05	60.00	59.09
0.8	80.00	79.07	0.1	71.11	70.45
Control	4.44		0.2	86.67	86.37
			Control	2.22	

Results obtained from probit analysis:
ES-Line
χ^2 (3) =1.708 (Not heterogeneous at P=0.05) Slope (b) = 2.111 $\pm$ 0.296
Regression equation: Y =2.111X + 1.596
LC_{50}=0.409 per cent Fiducial limits of LC_{50} = 0.337-0.497 per cent

NS-Line
χ^2 (4) = 1.101 (Not heterogeneous at P=0.05) Slope (b) = 1.148 $\pm$ 0.167
Regression equation: Y = 1.148 X + 3.340
LC_{50}=0.028 per cent Fiducial limits of LC_{50} = 0.013-0.031 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.24.

Data (Table 4.2.24) showed that endosulfan at 0.6 and 0.8 per cent concentration resulted into 62.79 and 79.07 per cent mortality of 3rd instar larvae of ES-Line in G_9. Hence 0.60 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.60
No. of larvae treated 200
No. of larvae dead = 123
Per cent mortality = 61.50

Table: 4.2.25 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_{10}

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.2	13.33	13.33	0.0125	26.67	26.67
0.4	26.67	26.67	0.025	48.89	48.89
0.6	53.33	53.33	0.05	64.44	64.44
0.8	71.11	71.11	0.1	73.33	73.33
1.0	88.89	88.89	0.2	88.89	88.89
Control	0.00		Control	0.00	

Results obtained from probit analysis:

ES-Line

χ^2 (3) = 3.803 (Not heterogeneous at P=0.05) Slope (b) = 3.228 $\pm$ 0.131

Regression equation: Y = 3.228 X – 0.562

LC_{50}=0.528 per cent Fiducial limits of LC_{50} = 0.465-0.600 per cent

NS-Line

χ^2 (3) = 0.555 (Not heterogeneous at P=0.05) Slope (b) = 1.238 $\pm$ 0.223

Regression equation: Y = 1.238 X + 3.251

LC_{50}=0.026 per cent Fiducial limits of LC_{50} = 0.018-0.038 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.25.

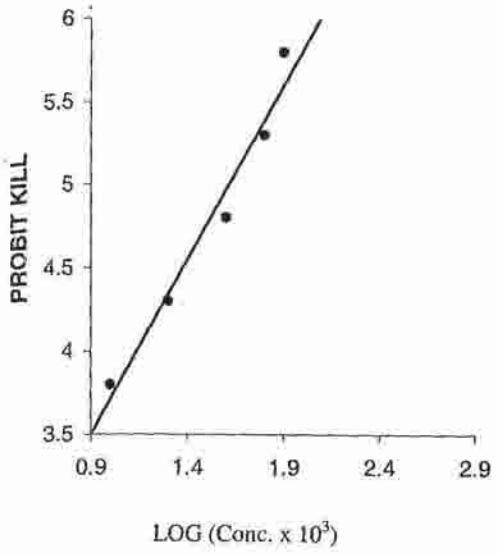
Data (Table 4.2.25) showed that there was 71.11 and 88.89 per cent mortality at 0.8 and 1.0 per cent of 3rd instar larvae of ES-Line in G_9 of endosulfan. Hence 0.75 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:

Conc. applied (%) = 0.75

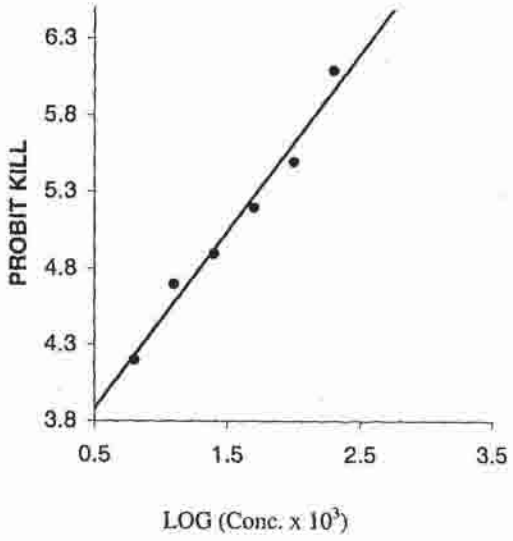
No. of larvae treated =200

No. of larvae dead = 136

Per cent mortality = 68.00

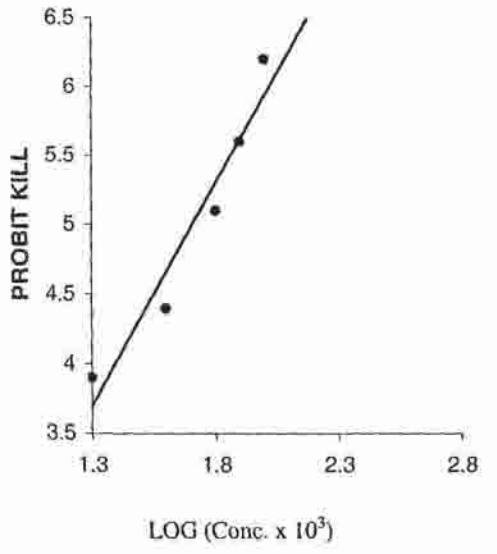


ES-Line

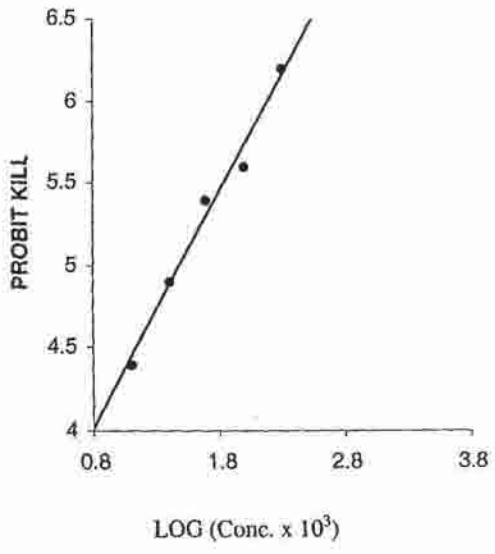


NS-Line

Fig. 4.2.24 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_9



ES-Line



NS-Line

Fig. 4.2.25 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_{10}

Table 4.2.26 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_{11}

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.2	10.00	6.89	0.00625	13.33	13.33
0.4	26.67	24.14	0.0125	33.33	33.33
0.6	50.00	48.28	0.025	46.67	46.67
0.8	66.67	65.52	0.05	66.67	66.67
1.0	86.67	86.21	0.1	73.33	73.33
Control	3.33		Control	0.00	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 2.058 (Not heterogeneous at P=0.05) Slope (b) = 3.609 $\pm$ 0.072
Regression equation: Y = 3.609 X – 1.382
LC_{50}=0.586 per cent Fiducial limits of LC_{50} = 0.521-0.659 per cent

NS-Line
χ^2 (3) = 1.541(Not heterogeneous at P=0.05) Slope (b) = 1.393 $\pm$ 0.234
Regression equation: Y = 1.393 X + 2.951
LC_{50}=0.029 per cent Fiducial limits of LC_{50} = 0.022-0.039 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.26.

Data (Table 4.2.26) showed that endosulfan at 0.8 per cent concentration resulted into 65.52 per cent mortality of 3rd instar larvae of ES-Line in G_{11}. Hence 0.80 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.80
No. of larvae treated 200
No. of larvae dead = 140
Per cent mortality = 70.00

Table: 4.2.27 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_{12}

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.4	22.22	22.22	0.00625	15.56	15.56
0.6	44.44	44.44	0.0125	37.78	37.78
0.8	62.22	62.22	0.025	51.11	51.11
1.0	84.44	84.44	0.05	68.89	68.89
2.0	93.33	93.33	0.1	77.78	77.78
Control	0.00		Control	0.00	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 2.510 (Not heterogeneous at P=0.05) Slope (b) = 3.537 $\pm$ 0.477
Regression equation: Y = 3.537 X – 1.373
LC_{50}= 0.634 per cent Fiducial limits of LC_{50} = 0.559-0.719 per cent

NS-Line
χ^2 (3) = 1.319(Not heterogeneous at P=0.05) Slope (b) = 1.429 $\pm$ 0.224
Regression equation: Y = 1.429 X + 3.004
LC_{50}=0.025 per cent Fiducial limits of LC_{50} = 0.019-0.033 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.27.

Data (Table 4.2.27) showed that there was 62.22 per cent mortality at 0.8 per cent of 3rd instar larvae of ES-Line in G_{12} of endosulfan. Hence 0.80 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.80
No. of larvae treated =200
No. of larvae dead = 130
Per cent mortality = 65.00

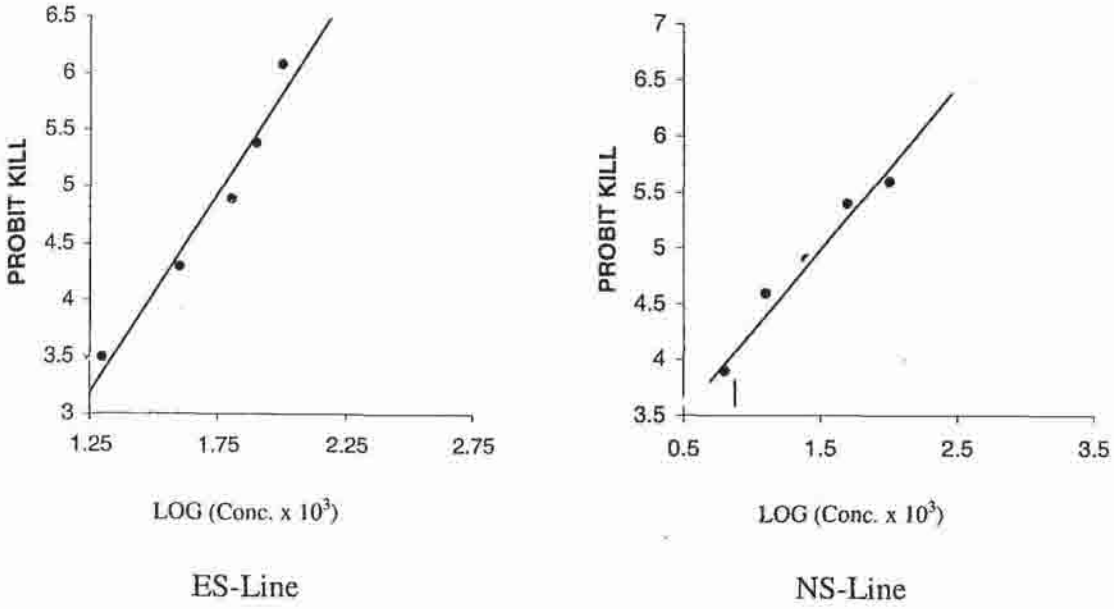


Fig. 4.2.26 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_{11}

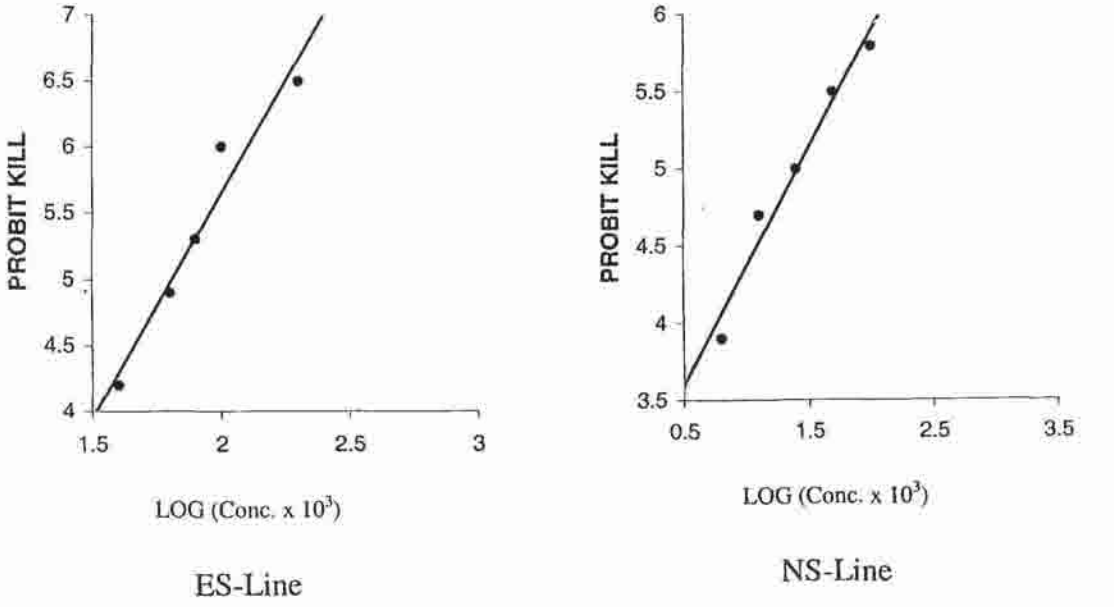


Fig. 4.2.27 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_{12}

Table: 4.2.28 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_{13}

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.4	24.44	20.93	0.00625	24.44	20.93
0.6	46.67	44.19	0.0125	42.22	39.54
0.8	60.00	58.14	0.025	53.33	51.16
1.0	82.22	81.39	0.05	62.22	60.46
2.0	91.11	90.70	0.1	73.33	72.09
Control	4.44		0.2	88.89	88.37
			Control	4.44	

Results obtained from probit analysis:
ES-Line
χ^2 (3) = 3.145 (Not heterogeneous at P=0.05) Slope (b) = 3.261 $\pm$ 0.476
Regression equation: Y = 3.261 X – 0.938
LC_{50}=0.662 per cent Fiducial limits of LC_{50} = 0.588-0.765 per cent

NS-Line
χ^2 (4) = 1.372(Not heterogeneous at P=0.05) Slope (b) = 1.179 $\pm$ 0.176
Regression equation: Y = 1.179 X + 3.383
LC_{50}=0.024 per cent Fiducial limits of LC_{50} = 0.016-0.028 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.28.

Data (Table 4.2.28) showed that there was 58.14 and 81.39 per cent mortality at 0.8 and 1.0 per cent of 3rd instar larvae of ES-Line in G_{13} of endosulfan. Hence 0.90 per cent concentration of endosulfan was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.90
No. of larvae treated =200
No. of larvae dead = 142
Per cent mortality = 71.00

Table: 4.2.29 Toxicity of endosulfan to larvae of ES- and NS- lines of *P. xylostella* in G_{14}

ES Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.4	20.00	20.00	0.00625	17.78	17.78
0.6	44.44	44.44	0.0125	37.78	37.78
0.8	55.56	55.56	0.025	55.56	55.56
1.0	77.78	77.78	0.05	68.89	68.89
2.0	86.67	86.67	0.1	77.78	77.78
Control	0.00		Control	0.00	

Results obtained from probit analysis:

ES-Line

χ^2 (3) = 3.763 (Not heterogeneous at P=0.05) Slope (b) =2.908 $\pm$ 0.455

Regression equation: Y = 2.908 X – 0.347

LC_{50}=0.689 per cent Fiducial limits of LC_{50} = 0.596-0.799 per cent

NS-Line

χ^2 (3) = 1.220 (Not heterogeneous at P=0.05) Slope (b) = 1.371 $\pm$ 0.229

Regression equation: Y = 1.371 X + 3.123

LC_{50}=0.023 per cent Fiducial limits of LC_{50} = 0.017-0.032 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.29.

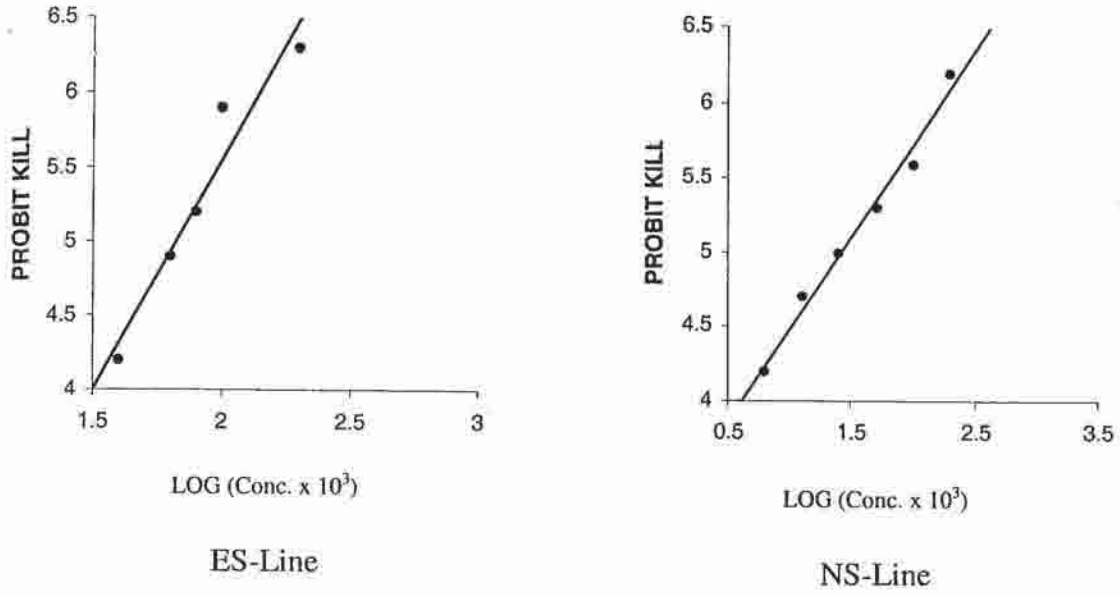


Fig. 4.2.28 Log (conc.) – probit mortality regression lines for endosulfan to the larvae of *P. xylostella* of the ES- and the NS- lines in G_{13}

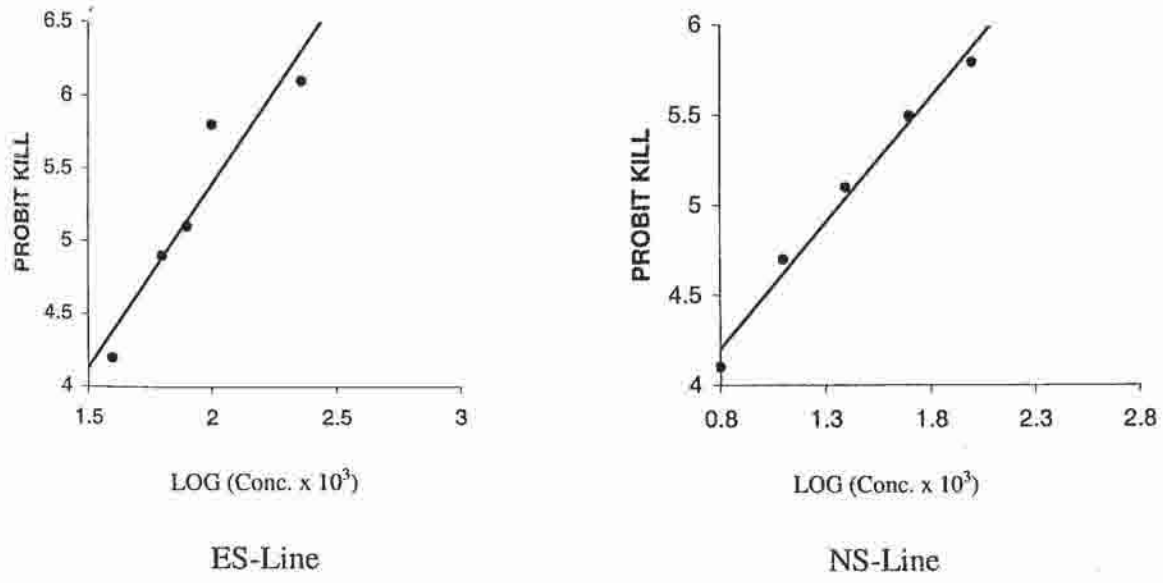


Fig. 4.2.29 Log (conc.) – probit mortality regression lines for endosulfan to the larvae *P. xylostella* of the ES- and the NS- lines in G_{14}

Table: 4.2.30 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_1

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0025	22.22	18.61	0.0025	17.78	17.78
0.005	35.56	32.57	0.005	33.33	33.33
0.01	57.78	55.82	0.01	48.89	48.89
0.02	68.89	67.44	0.02	64.44	64.44
0.04	82.22	81.39	0.04	86.67	86.67
Control	4.44		Control	0.00	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 0.229 (Not heterogeneous at P=0.05) Slope (b) = 1.585 $\pm$ 0.234
Regression equation: Y = 1.585 X + 3.426
LC_{50}=0.00979 per cent Fiducial limits of LC_{50} = 0.00753-0.01274 per cent

NS-Line
χ^2 (3) = 0.489 (Not heterogeneous at P=0.05) Slope (b) = 1.486 $\pm$ 0.221
Regression equation: Y = 1.486 X + 3.545
LC_{50}=0.00953 per cent Fiducial limits of LC_{50} = 0.00726-0.01250 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.30.

Data (Table 4.2.30) showed that there was 67.44 and 81.39 per cent mortality at 0.02 and 0.04per cent of 3rd instar larvae of FS-Line in $G_1$of fenvalerate. Hence 0.020 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.020
No. of larvae treated =200
No. of larvae dead = 130
Per cent mortality = 65.00

Table: 4.2.31 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_2

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0025	17.78	15.91	0.0025	24.44	24.44
0.005	26.67	25.00	0.005	33.33	33.33
0.01	51.11	50.00	0.01	57.77	57.77
0.02	64.44	63.63	0.02	66.66	66.66
0.04	77.78	77.28	0.04	80.00	80.00
Control	2.22		Control	0.00	

Results obtained from probit analysis:

FS-Line

χ^2 (3) = 0.699 (Not heterogeneous at P=0.05) Slope (b) = 1.504 $\pm$ 0.227

Regression equation: Y = 1.504 X + 3.385

LC_{50}=0.01185 per cent Fiducial limits of LC_{50}= 0.00902-0.01558 per cent

NS-Line

χ^2 (3) = 0.262 (Not heterogeneous at P=0.05) Slope (b) = 1.312 $\pm$ 0.217

Regression equation: Y = 1.312 X + 3.719

LC_{50}=0.00947 per cent Fiducial limits of LC_{50} = 0.00698-0.01283 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.31.

Data (Table 4.2.31) showed that fenvalerate at 0.02 per cent concentration resulted into 63.63 per cent mortality of 3rd instar larvae of FS-Line in G_2. Hence 0.02 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 0.02

No. of larvae treated 200

No. of larvae dead = 120

Per cent mortality = 60.00

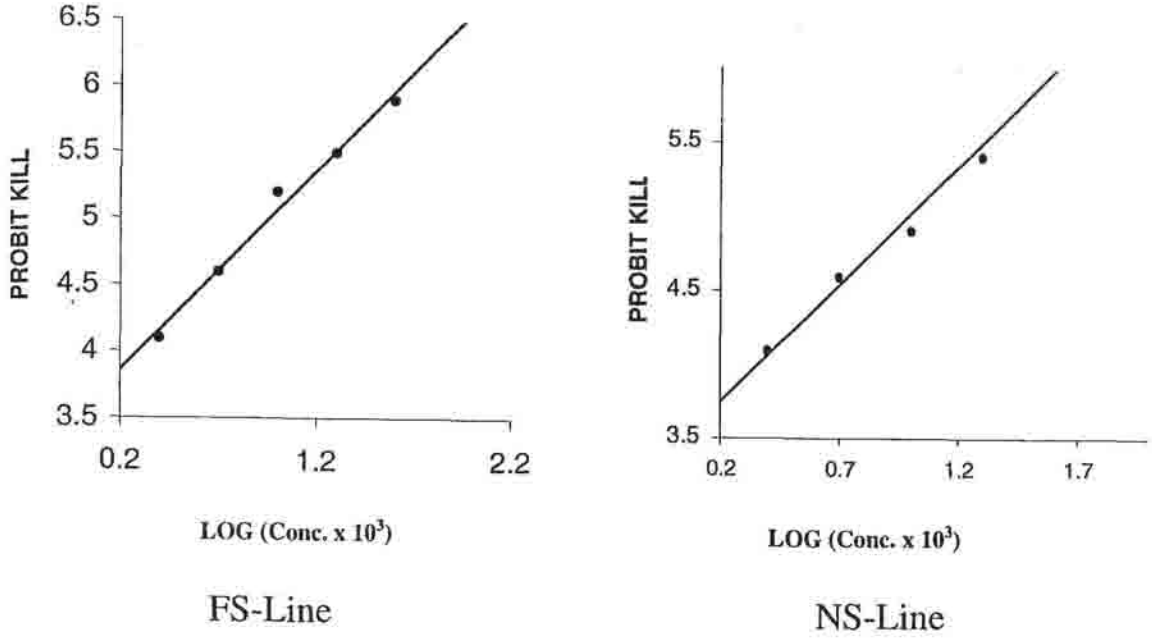


Fig. 4.2.30 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_1

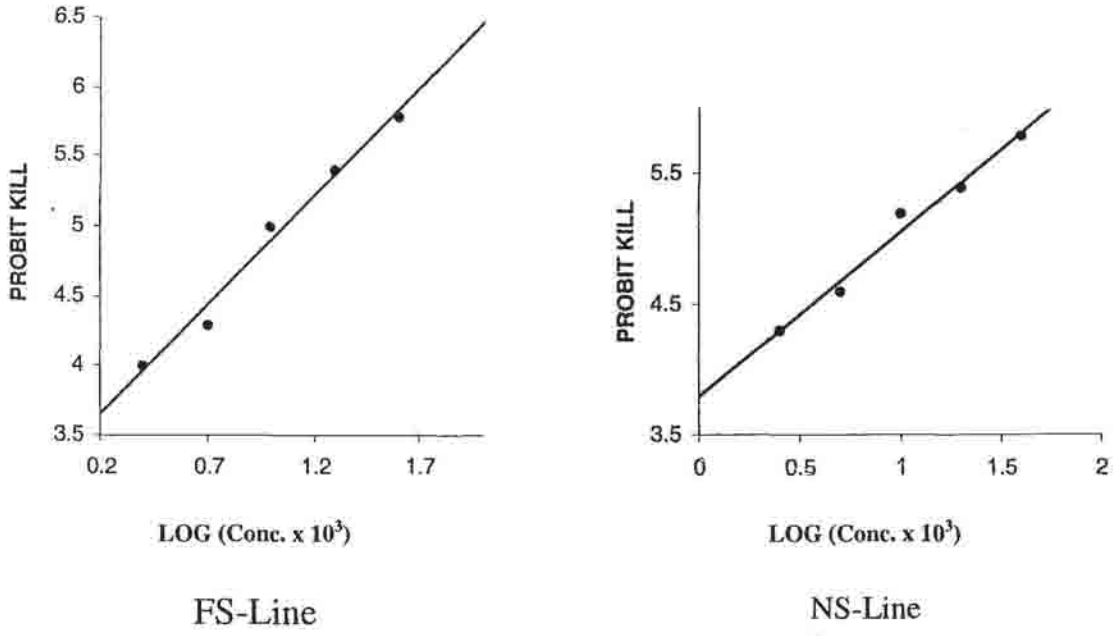


Fig. 4.2.31 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_2

Table: 4.2.32 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_3

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.003125	15.56	13.64	0.0025	24.44	20.92
0.00625	24.44	22.72	0.005	35.56	32.56
0.0125	51.11	50.00	0.01	57.78	55.82
0.025	68.89	68.18	0.02	71.11	69.77
0.05	84.44	84.09	0.04	82.22	81.39
Control	2.22		Control	4.44	

Results obtained from probit analysis:
FS-Line
χ^2 (3) =0.628 (Not heterogeneous at P=0.05) Slope (b) = 1.808 $\pm$ 0.235
Regression equation: Y = 1.808 X + 2.936
LC_{50}=0.01384 per cent Fiducial limits of LC_{50} = 0.01098-0.01743 per cent

NS-Line
χ^2 (3) = 0.445 (Not heterogeneous at P=0.05) Slope (b) = 1.484 $\pm$ 0.222
Regression equation: Y = 1.484 X + 3.573
LC_{50}=0.00916 per cent Fiducial limits of LC_{50} = 0.00697-0.01203 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.32.

Data (Table 4.2.32) showed that there was 68.18 per cent mortality at 0.025 per cent of 3rd instar larvae of FS-Line in G_2 of fenvalerate. Hence 0.025 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.025
No. of larvae treated =200
No. of larvae dead = 134
Per cent mortality = 67.00

Table: 4.2.33 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_4

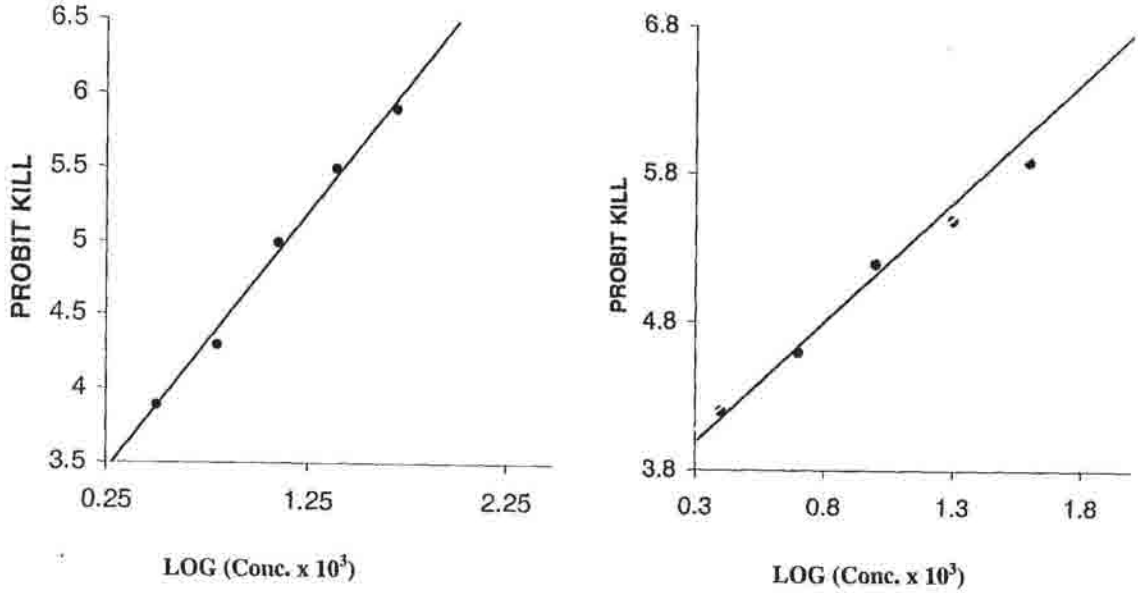
FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.00625	24.44	20.93	0.0025	22.22	22.22
0.0125	40.00	37.21	0.005	40.00	40.00
0.025	57.78	55.82	0.01	53.33	53.33
0.05	71.11	69.77	0.02	73.33	73.33
0.1	93.33	93.02	0.04	84.44	84.44
Control	4.44		Control	0.00	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 1.758 (Not heterogeneous at P=0.05) Slope (b) = 1.679 $\pm$ 0.230
Regression equation: Y = 1.679 X + 2.829
LC_{50}=0.01965 per cent Fiducial limits of LC_{50} = 0.01528-0.02525 per cent

NS-Line
χ^2 (3) = 0.218 (Not heterogeneous at P=0.05) Slope (b) = 1.469 $\pm$ 0.224
Regression equation: Y = 1.469 X + 3.669
LC_{50}=0.00804 per cent Fiducial limits of LC_{50} = 0.00607-0.01065 per cent

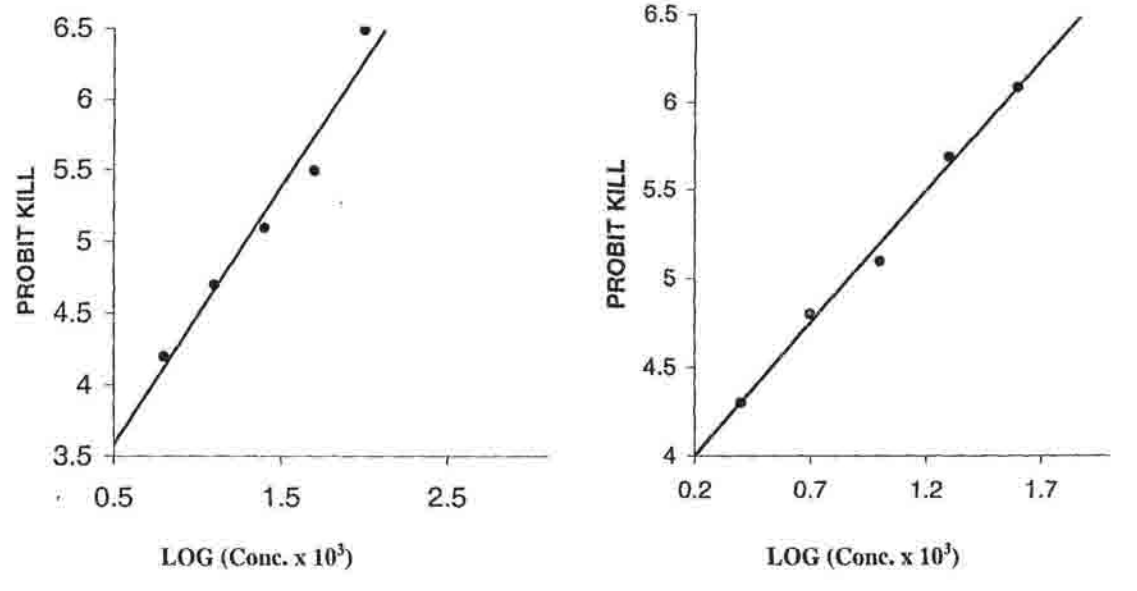
The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.33.

Data (Table 4.2.33) showed that fenvalerate at 0.05 per cent concentration resulted into 69.77 per cent mortality of 3rd instar larvae of FS-Line in G_4. Hence 0.05 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.05
No. of larvae treated 200
No. of larvae dead = 150
Per cent mortality = 75.00



FS-Line NS-Line

Fig. 4.2.32 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_3



FS-Line NS-Line

Fig. 4.2. 33 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_4

Table: 4.2.34 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_5

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.00625	22.22	16.67	0.0025	26.67	21.43
0.0125	42.22	38.09	0.005	40.00	35.71
0.025	55.56	53.38	0.01	60.00	57.14
0.05	66.67	64.29	0.02	75.56	73.80
0.1	86.67	85.71	0.04	86.67	85.72
Control	6.67		Control	6.67	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 1.187 (Not heterogeneous at P=0.05) Slope (b) = 1.537 $\pm$ 0.221
Regression equation: Y = 1.537 X + 2.895
LC_{50}=0.02343 per cent Fiducial limits of LC_{50} = 0.01800-0.03049 per cent

NS-Line
χ^2 (3) = 0.145 (Not heterogeneous at P=0.05) Slope (b) = 1.571 $\pm$ 0.226
Regression equation: Y = 1.571 X + 3.578
LC_{50}=0.00844 per cent Fiducial limits of LC_{50} = 0.00564-0.01146 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.34.

Data (Table 4.2.34) showed that there was 64.29 per cent mortality at 0.05 per cent of 3rd instar larvae of FS-Line in G_5 of fenvalerate. Hence 0.05 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.05
No. of larvae treated =200
No. of larvae dead = 130
Per cent mortality = 65.00

Table: 4.2.35 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_6

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.00625	17.78	15.91	0.0025	28.89	21.95
0.0125	35.56	34.09	0.005	42.22	36.58
0.025	44.44	43.18	0.01	62.22	58.54
0.05	57.78	56.82	0.02	77.78	75.61
0.1	80.00	79.55	0.04	88.89	87.81
Control	2.22		Control	8.89	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 1.258 (Not heterogeneous at P=0.05) Slope (b) = 1.385 $\pm$ 0.219
Regression equation: Y = 1.385 X + 2.939
LC_{50}=0.03074 per cent Fiducial limits of LC_{50} = 0.02294-0.04118 per cent

NS-Line
χ^2 (3) = 0.092 (Not heterogeneous at P=0.05) Slope (b) = 1.633 $\pm$ 0.230
Regression equation: Y = 1.633 X + 3.557
LC_{50}=0.00765 per cent Fiducial limits of LC_{50} = 0.00543-0.00963 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.35.

Data (Table 4.2.35) showed that there was 56.82 and 79.55 per cent mortality at 0.05 and 0.1 per cent of 3rd instar larvae of FS-Line in G_6 of fenvalerate. Hence 0.075 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.075
No. of larvae treated =200
No. of larvae dead = 126
Per cent mortality = 63.00

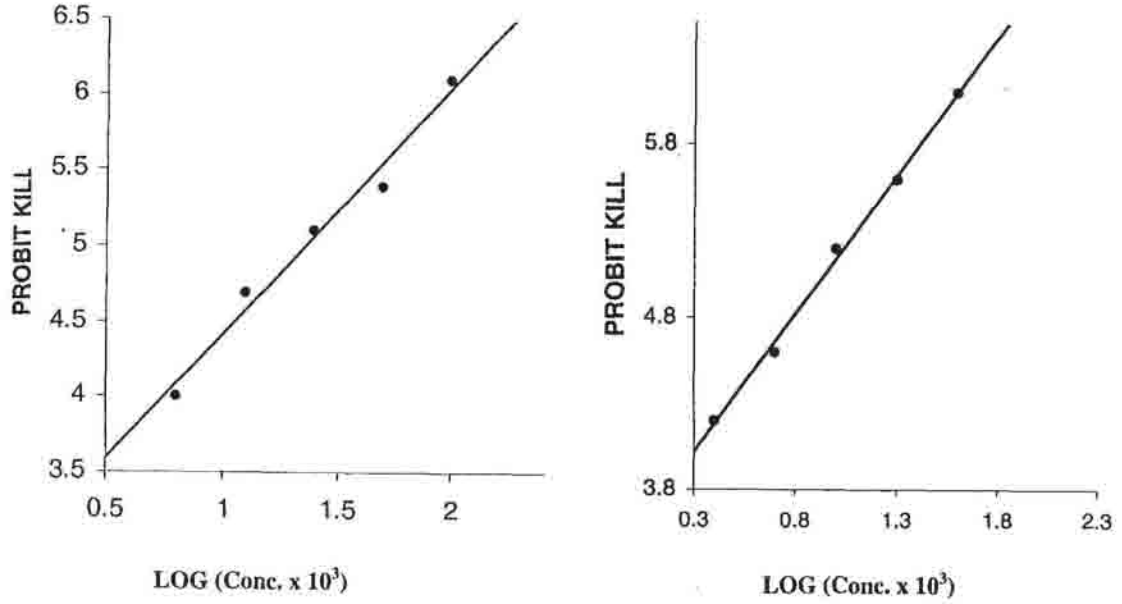


Fig. 4.2.34 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_5

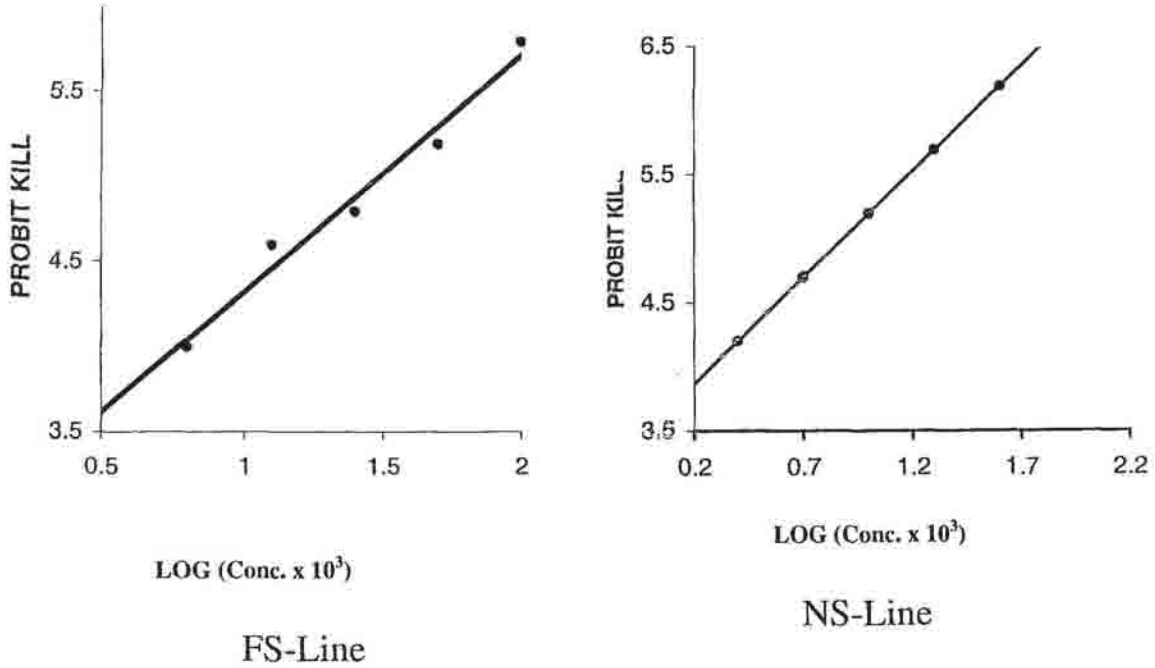


Fig. 4.2.35 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_6

Table: 4.2.36Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_7

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0125	26.67	23.26	0.0025	28.89	28.89
0.025	37.78	34.88	0.005	35.56	35.56
0.05	51.11	48.84	0.01	60.00	60.00
0.1	71.11	69.77	0.02	68.89	68.89
0.2	95.56	95.35	0.04	82.89	82.89
Control	4.44		Control	0.00	

Results obtained from probit analysis:
FS-Line
χ^2 (3) =4.878 (Not heterogeneous at P=0.05) Slope (b) = 1.751 $\pm$ 0.246
Regression equation: Y = 1.751 X + 2.174
LC_{50}=0.04109 per cent Fiducial limits of LC_{50} = 0.03217-0.05246 per cent

NS-Line
χ^2 (3) = 0.963 (Not heterogeneous at P=0.05) Slope (b) = 1.272 $\pm$ 0.218
Regression equation: Y = 1.272 X + 3.877
LC_{50}=0.00763 per cent Fiducial limits of LC_{50} = 0.00491-0.01186 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.36.

Data (Table 4.2.36) showed that fenvalerate at 0.1 per cent concentration resulted into 69.77 per cent mortality of 3rd instar larvae of FS-Line in G_7. Hence 0.1per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.10
No. of larvae treated 200
No. of larvae dead = 144
Per cent mortality = 72.00

Table: 4.2.37 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_8

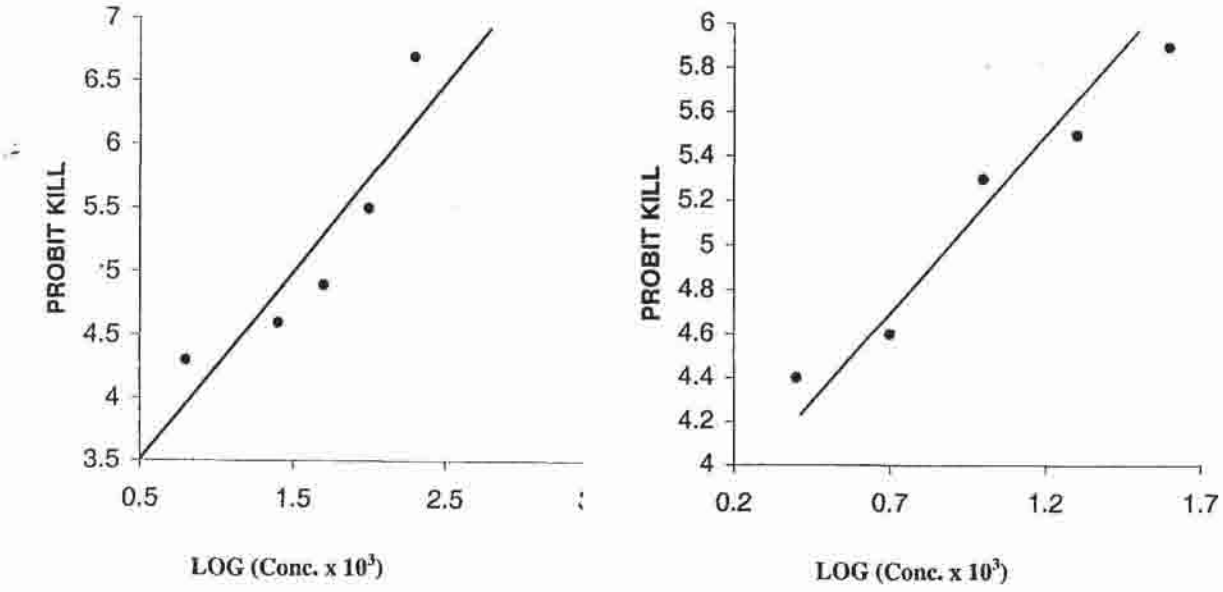
FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0125	22.22	22.22	0.0025	24.44	24.44
0.025	31.11	31.11	0.005	42.22	42.22
0.05	44.44	44.44	0.01	55.56	55.56
0.1	66.67	66.67	0.02	75.56	75.56
0.2	88.89	88.89	0.04	86.67	86.67
Control	0.00		Control	0.00	

Results obtained from probit analysis:
FS-Line
χ^2 (3) =2.307(Not heterogeneous at P=0.05) Slope (b) = 1.579 $\pm$ 0.223
Regression equation: Y = 1.579 X + 2.336
LC_{50}=0.04862 per cent Fiducial limits of LC_{50} = 0.03761-0.06284 per cent

NS-Line
χ^2 (3) = 0.219 (Not heterogeneous at P=0.05) Slope (b) = 1.486 $\pm$ 0.228
Regression equation: Y = 1.486X + 3.723
LC_{50}=0.00723 per cent Fiducial limits of LC_{50} = 0.00590-0.00992 per cent

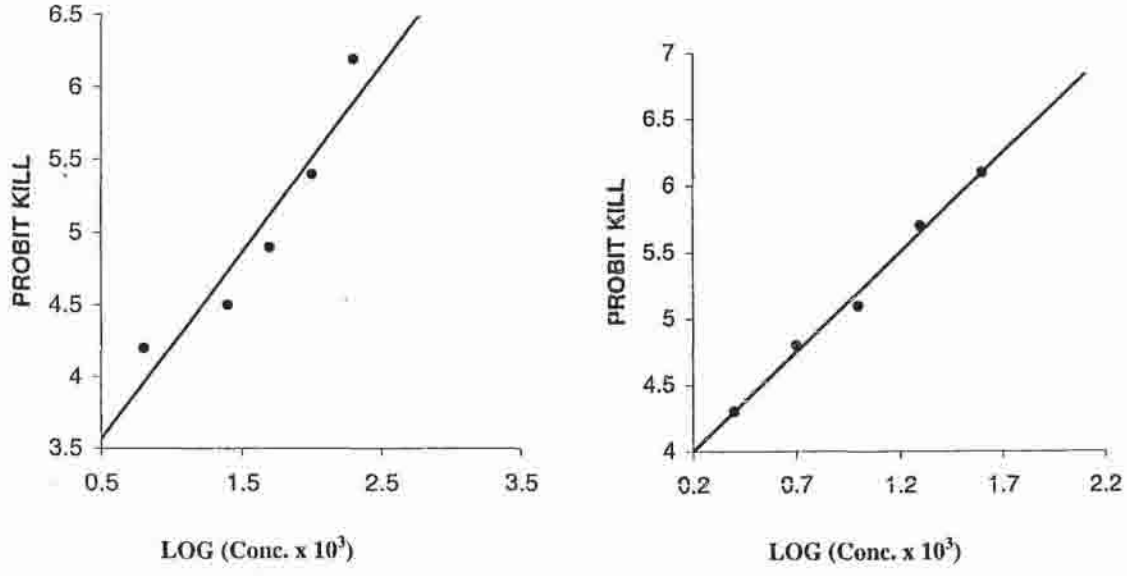
The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.37.

Data (Table 4.2.37) showed that fenvalerate at 0.1 per cent concentration resulted into 66.67 per cent mortality of 3rd instar larvae of FS-Line in G_8. Hence 0.1 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:
Conc. applied (%) = 0.10
No. of larvae treated 200
No. of larvae dead = 136
Per cent mortality = 68.00



FS-Line NS-Line

Fig. 4.2.36 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_7



FS-Line NS-Line

Fig. 4.2.37 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_8

Table: 4.2.38 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_9

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0125	17.78	13.96	0.0025	22.22	22.22
0.025	26.67	23.26	0.005	44.44	44.44
0.05	37.78	34.89	0.01	57.78	57.78
0.1	62.22	60.46	0.02	77.78	77.78
0.2	84.44	83.72	0.04	84.44	84.44
Control	4.44		Control	0.00	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 1.815 (Not heterogeneous at P=0.05) Slope (b) = 1.695 $\pm$ 0.232
Regression equation: Y = 1.695 X + 1.905
LC_{50}=0.06689 per cent Fiducial limits of LC_{50} = 0.05223-0.08566 per cent

NS-Line
χ^2 (3) = 0.798 (Not heterogeneous at P=0.05) Slope (b) = 1.475 $\pm$ 0.230
Regression equation: Y = 1.475 X + 3.747
LC_{50}=0.00707 per cent Fiducial limits of LC_{50} = 0.00527-0.00948 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.38.

Data (Table 4.2.38) showed that there was 60.46 and 83.72 per cent mortality at 0.1 and 0.2 per cent of 3rd instar larvae of FS-Line in G_9 of fenvalerate. Hence 0.15 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.15
No. of larvae treated =150
No. of larvae dead = 96
Per cent mortality = 64.00

Table: 4.2.39 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_{10}

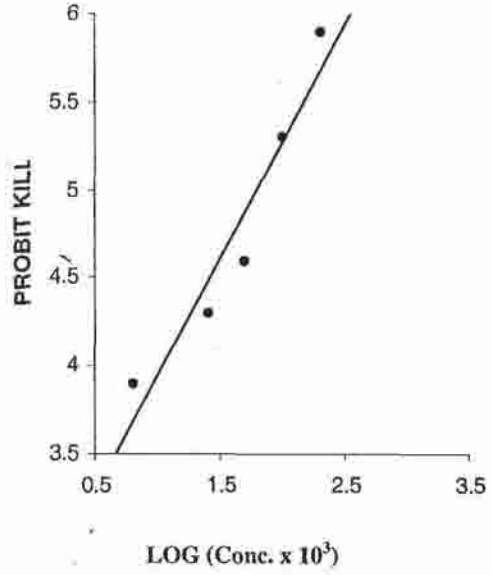
FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0125	17.78	11.90	0.0025	26.67	23.25
0.025	22.22	16.67	0.005	46.67	44.19
0.05	35.56	30.95	0.01	57.78	55.81
0.1	57.78	54.76	0.02	77.78	76.74
0.2	80.00	78.57	0.04	88.89	88.37
Control	6.67		Control	4.44	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 8.306 (Not heterogeneous at P=0.05) Slope (b) = 1.727 $\pm$ 0.201
Regression equation: Y = 1.727 X + 1.621
LC_{50}=0.09055 per cent Fiducial limits of LC_{50} = 0.07143-0.11470 per cent

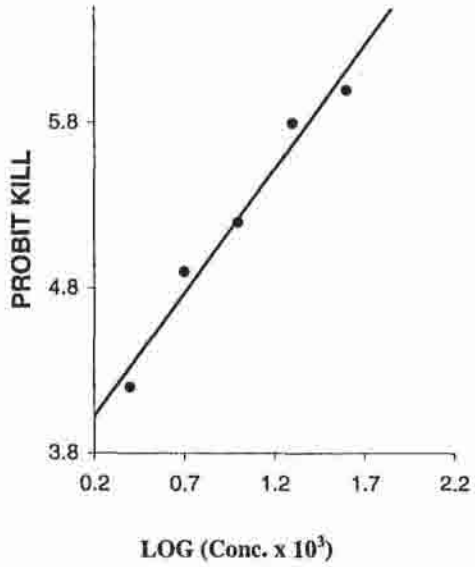
NS-Line
χ^2 (3) = 0.469 (Not heterogeneous at P=0.05) Slope (b) = 1.549 $\pm$ 0.235
Regression equation: Y = 1.549 X + 3.691
LC_{50}=0.00700 per cent Fiducial limits of LC_{50} = 0.00528-0.00928 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.39.

Data (Table 4.2.39) showed that there was 54.76 and 78.57 per cent mortality at 0.1 and 0.2 per cent of 3rd instar larvae of FS-Line in G_{10} of fenvalerate. Hence 0.15 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:
Conc. applied (%) = 0.15
No. of larvae treated =150
No. of larvae dead = 92
Per cent mortality = 61.33

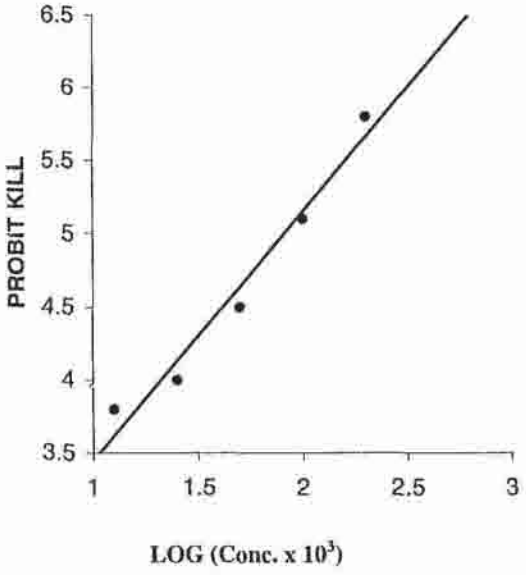


FS-Line

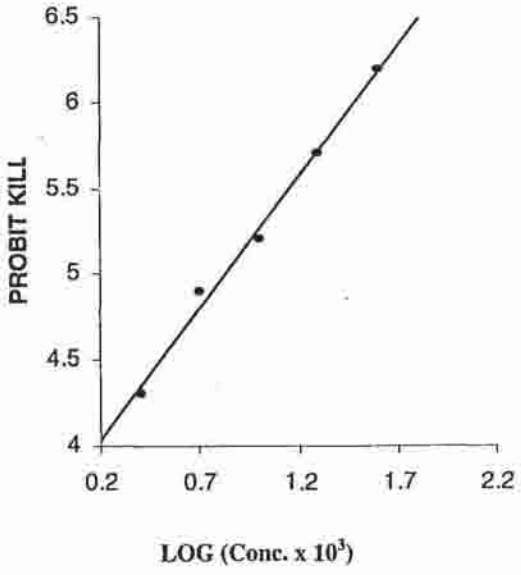


NS-Line

Fig. 4.2.38 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_9



FS-Line



NS-Line

Fig. 4.2.39 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- ines in G_{10}

Table: 4.2.40 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_{11}

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	17.78	15.90	0.0025	28.89	28.89
0.05	28.89	27.26	0.005	42.22	42.22
0.1	53.33	52.27	0.01	60.00	60.00
0.2	75.56	74.99	0.02	73.33	73.33
0.4	88.89	88.62	0.04	80.00	80.00
Control	2.22		Control	0.00	

Results obtained from probit analysis:

FS-Line

χ^2 (3) = 0.692 (Not heterogeneous at P=0.05) Slope (b) = 1.913 $\pm$ 0.241

Regression equation: Y = 1.913 X + 1.228

LC_{50}=0.09366 per cent Fiducial limits of LC_{50} = 0.05901-0.09929 per cent

NS-Line

χ^2 (3) = 0.372 (Not heterogeneous at P=0.05) Slope (b) = 1.186 $\pm$ 0.216

Regression equation: Y = 1.186 X + 4.017

LC_{50}=0.00674 per cent Fiducial limits of LC_{50} = 0.00475-0.00956 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.40.

Data (Table 4.2.40) showed that fenvalerate at 0.2 per cent concentration resulted into 74.99 per cent mortality of 3rd instar larvae of FS-Line in G_{11}. Hence 0.2 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3rd instar larvae. Details are as follow:

Conc. applied (%) = 0.20

No. of larvae treated 150

No. of larvae dead = 104

Per cent mortality = 69.33

Table: 4.2.41 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_{12}

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.025	15.56	13.64	0.0025	31.11	31.11
0.05	26.67	25.00	0.005	37.78	37.78
0.1	51.11	50.00	0.01	62.22	62.22
0.2	71.11	70.45	0.02	71.11	71.11
0.4	86.67	86.37	0.04	80.00	80.00
Control	2.22		Control	0.00	

Results obtained from probit analysis:
FS-Line
χ^2 (3) = 0.249 (Not heterogeneous at P=0.05) Slope (b) = 1.871 $\pm$ 0.242
Regression equation: Y = 1.871 X + 1.230
LC_{50}=0.10355 per cent Fiducial limits of LC_{50} = 0.08256-0.12985 per cent

NS-Line
χ^2 (3) = 1.090 (Not heterogeneous at P=0.05) Slope (b) = 1.184 $\pm$ 0.216
Regression equation: Y = 1.184 X + 3.999
LC_{50}=0.00700 per cent Fiducial limits of LC_{50} = 0.00402-0.00997 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.41.

Data (Table 4.2.41) showed that there was 70.45 per cent mortality at 0.2 per cent of 3rd instar larvae of FS-Line in G_{12} of fenvalerate. Hence 0.20 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow: .
Conc. applied (%) = 0.15
No. of larvae treated =150
No. of larvae dead = 97
Per cent mortality = 64.66

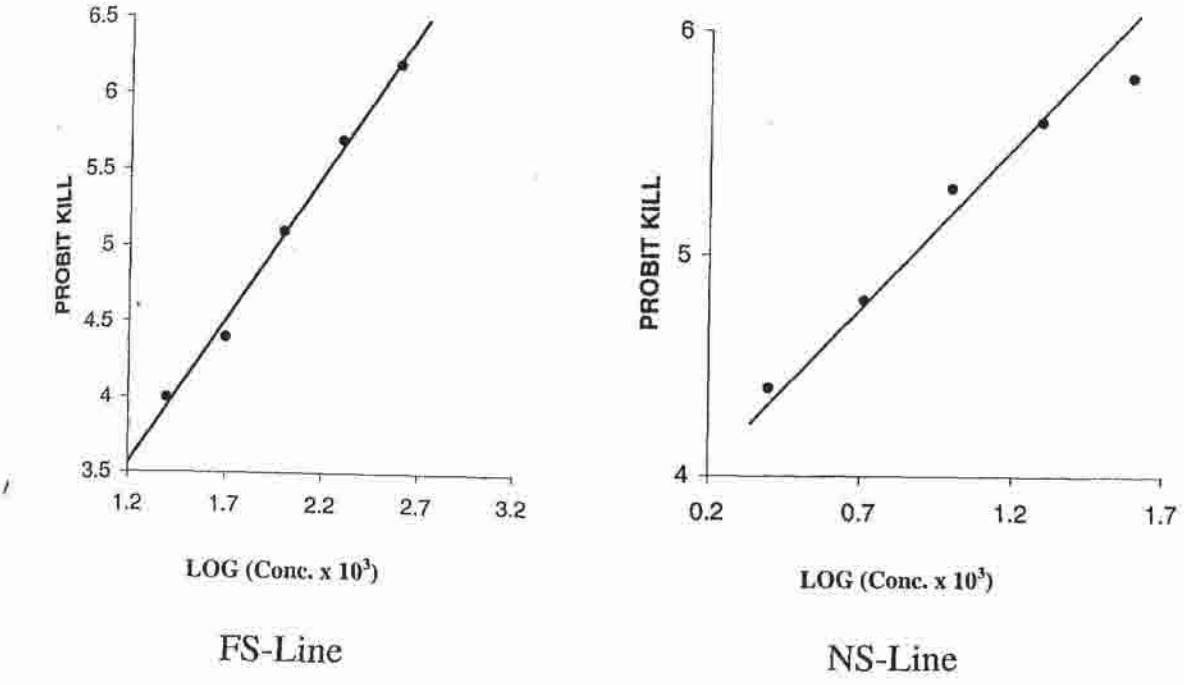


Fig. 4.2.40 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_{11}

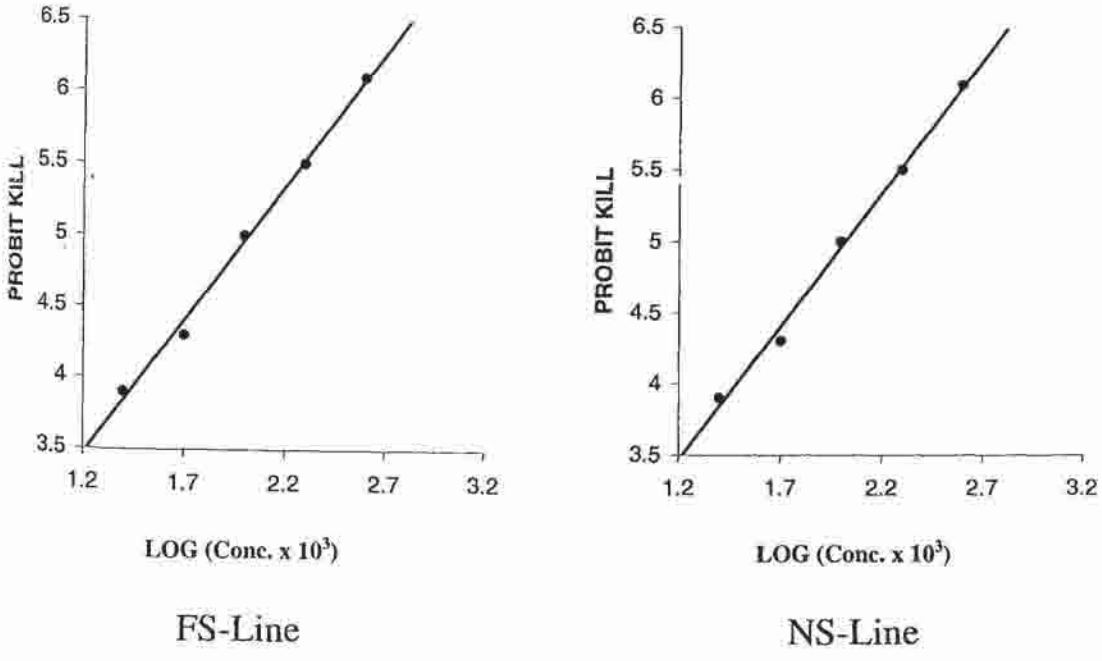


Fig. 4.2.41 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_{12}

Table: 4.2.42 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_{13}

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.03125	20.00	16.28	0.0025	40.00	34.15
0.0625	31.11	27.91	0.005	48.88	43.89
0.125	55.56	53.48	0.01	68.88	65.84
0.25	77.78	76.75	0.02	80.00	78.05
0.5	93.33	93.02	0.04	93.33	92.68
Control	4.44		Control	8.89	

Results obtained from probit analysis:

FS-Line

χ^2 (3) =0.955 (Not heterogeneous at P=0.05) Slope (b) = 2.023 $\pm$ 0.268

Regression equation: Y = 2.023 X + 2.908

LC_{50}=0.10806 per cent Fiducial limits of LC_{50} = 0.08662-0.13507 per cent

NS-Line

χ^2 (3) = 1.022 (Not heterogeneous at P=0.05) Slope (b) = 1.505 $\pm$ 0.232

Regression equation: Y = 1.505 X + 3.897

LC_{50}=0.00541 per cent Fiducial limits of LC_{50} = 0.00397-0.00736 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.42.

Data (Table 4.2.42) showed that there was 76.75 per cent mortality at 0.25 per cent of 3rd instar larvae of FS-Line in G_{13} of fenvalerate. Hence 0.25 per cent concentration of fenvalerate was choosen to have a selection pressure of 60-80 per cent kill of 3 rd instar larvae. Details are as follow:

Conc. applied (%) = 0.25

No. of larvae treated =105

No. of larvae dead = 73

Per cent mortality = 70.00

Table: 4.2.43 Toxicity of fenvalerate to larvae of FS- and NS- lines of *P. xylostella* in G_{14}

FS Line			NS Line		
Per cent Concentration	Per cent mortality	Per cent corrected mortality	Per cent Concentration	Per cent mortality	Per cent corrected mortality
0.0625	22.22	16.67	0.00125	13.33	13.33
0.125	35.56	30.95	0.0025	26.67	26.67
0.25	60.00	57.14	0.005	37.78	37.78
0.5	77.78	76.19	0.01	53.33	53.33
1.0	93.33	92.85	0.02	66.67	66.67
Control	6.67		0.04	77.78	77.78
			Control	0.00	

Results obtained from probit analysis:

FS-Line

χ^2 (3) = 0.448 (Not heterogeneous at P=0.05) Slope (b) = 2.002 $\pm$ 0.251

Regression equation: Y = 2.002 X + 2.964

LC_{50}=0.10409 per cent Fiducial limits of LC_{50} = 0.08382-0.12925 per cent

NS-Line

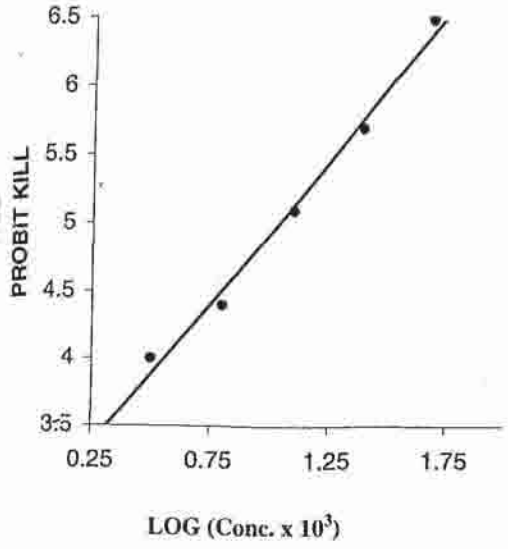
χ^2 (4) =0.654 (Not heterogeneous at P=0.05) Slope (b) = 1.234 $\pm$ 0.169

Regression equation: Y = 1.234 X + 4.069

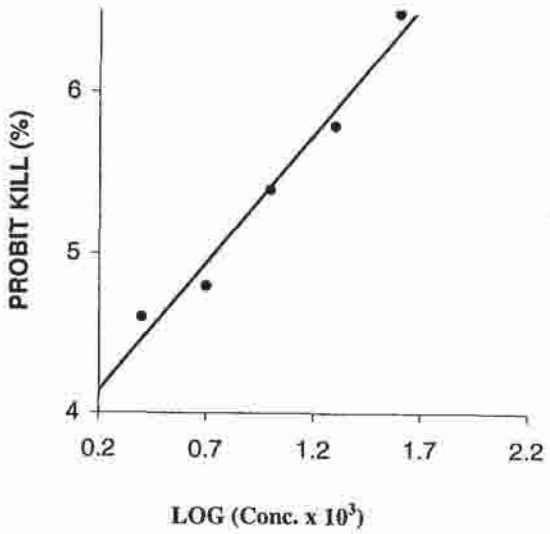
LC_{50}=0.00567 per cent Fiducial limits of LC_{50} = 0.00418-0.00769 per cent

The log (Concentration)- probit mortality regression lines are presented in Fig. 4.2.43.

fenvalerate was comparatively slower in the initial generations of selection but fast to malathion and endosulfan. In general, tendency/ability of *P. xylostella* to development resistance to malathion and endosulfan was higher than fenvalerate.

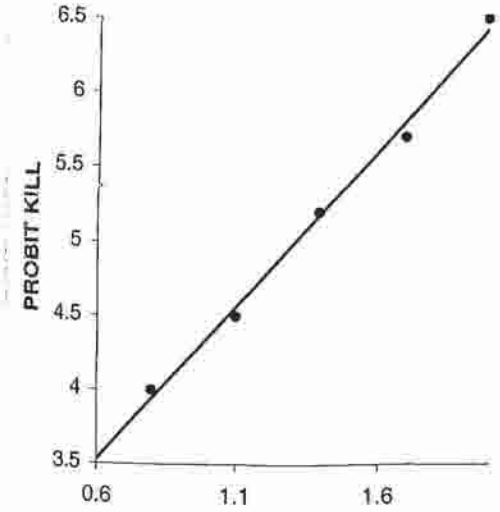


FS-Line

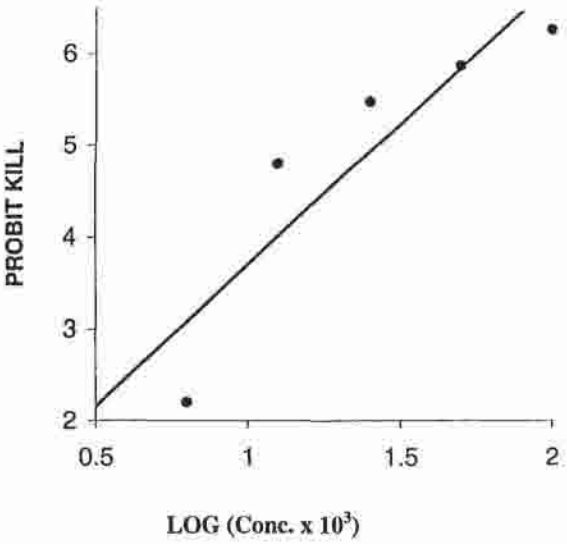


NS-Line

Fig. 4.2.42 Log (conc.)- probit mortality regression lines for fenvalerate to larvae of *P. xylostella* of the FS- and NS- lines in G_{13}



FS-Line



NS-Line

Fig. 4.2.43 Log (conc.)- probit mortality regression lines for fenvalerate to 3rd instar larvae of *P. xylostella* of the FS- and NS- lines in G_{14}

4.3 Cross-resistance patterns of resistant strains of *P. xylostella*

After the development of strains resistant to malathion, endosulfan and fenvalerate, a number of insecticides belonging to pyrethroids, organophosphates and cyclodienes were tested against resistant and susceptible strains for determining the cross-resistance spectrum of resistant strains. All the insecticides were tested by Direct Spray Method, the details of which are given in 'Material and Methods'.

4.3.1 Cross-resistance of malathion-resistant strain

Insecticides belonging to different groups were tested against malathion-resistant strain of *P. xylostella*. The LC_{50} values of cypermethrin, fenvalerate, monocrotophos, endosulfan and lambda -cyhalothrin, were estimated to be 0.01109, 0.01220, 0.046, 0.083 and 0.00502 per cent to the resistant and 0.00810, 0.00567, 0.020, 0.023, and 0.00351 per cent to the susceptible strain (Tables 4.3.1 to 4.3.4). Data showed an increase of the LC_{50} for the malathion-resistant strain over that for the susceptible strain (the S-strain). There were no significant differences in between the two strains for their susceptibility to cypermethrin and lambda-cyhalothrin and for fenvalerate, monocrotophos and endosulfan the strains differed significantly. The order of increase was: cypermethrin, 1.37; fenvalerate, 2.15; monocrotophos, 2.30; endosulfan, 3.61; and lambda-cyhalothrin 1.43 (Table 4.3.7). Thus, the MR- strain showed cross-resistance ranging between 1.37 and 3.61 to these insecticides.

4.3.2 Cross-resistance of endosulfan-resistant strain

Data presented in Tables 4.3.1 to 4.3.6 and summarised in Table 4.3.7 showed that the LC_{50} values of cypermethrin, fenvalerate, monocrotophos, malathion, and lambda-cyhalothrin were 0.00868, 0.00970, 0.029, 0.070, and 0.00403 per cent to the resistant and 0.00810, 0.00567, 0.020, 0.031, and 0.00351 per cent to the susceptible strain, respectively. There

were no significant differences between endosulfan-resistant and susceptible strains for their susceptibility to cypermethrin, fenvalerate, monocrotophos and lambda-cyhalothrin. However, there were significant differences between the two strains for their susceptibility to malathion. The order of increase of the LC_{50} for endosulfan-resistant strain over the susceptible strain was 1.07, 1.71, 1.38, 2.26, and 1.15 for the cypermethrin, fenvalerate, monocrotophos, malathion, and lambda-cyhalothrin, respectively.

4.3.3 Cross- resistance of fenvalerate-resistant strain

The LC_{50} values of cypermethrin, endosulfan, monocrotophos, malathion and lambda-cyhalothrin were 0.01843, 0.067, 0.024, 0.052, and 0.00453 per cent to the resistant and 0.00810, 0.023, 0.020, 0.031, and 0.00351 per cent to the susceptible strains, respectively (Tables 4.3.1 to 4.3.6 and summarised in Table 4.3.7). The comparison of these values showed an increase of the LC_{50} for the fenvalerate-resistant strain over that for the susceptible strain (the S-strain). Fenvalerate-resistant and susceptible strains were found significantly different for their susceptibility to cypermethrin and endosulfan. For other insecticides difference between the two strains were found non- significant. Resistance ratio for cypermethrin, endosulfan, monocrotophos, malathion and lambda-cyhalothrin were observed 2.28, 2.91, 1.15, 1.68 and 1.29, respectively.

Table: 4.3.1 Toxicity of malathion to larvae of the ER-, the FR- and the S- strains of *P. xylostella*

ER- strain			FR- strain			S-strain		
Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality
0.0125	20.00	20.00	0.0125	20.00	20.00	0.00625	26.66	23.25
0.025	26.67	26.67	0.025	35.56	35.56	0.0125	44.44	41.86
0.05	44.44	44.44	0.05	53.33	53.33	0.025	71.11	69.77
0.1	60.00	60.00	0.1	66.67	66.67	0.05	82.22	81.39
0.2	82.22	82.22	0.2	91.11	91.11	0.1	91.00	90.58
Control	0.00		Control	0.00		Control	4.44	

Results obtained from probit analysis:

χ^2 (3) = 1.187
(Not heterogeneous at P=0.05)
Slope (b) = 1.402 ± 0.022
Regression equation: y=1.402x + 2.417

LC_{50}=0.070
Fiducial limits of LC_{50} = 0.046-0.078

χ^2 (3) = 1.487
(Not heterogeneous at P=0.05)
Slope (b) = 1.650 ± 0.229
Regression equation: y=1.650x + 2.169
LC_{50}=0.052
Fiducial limits of LC_{50} = 0.034-0.055

χ^2 (3) = 0.788
(Not heterogeneous at P=0.05)
Slope (b) = 1.754 ± 0.235
Regression equation: y=1.754x + 2.382
LC_{50}=0.031
Fiducial limits of LC_{50} = 0.024-0.040

The log (concentration)-probit mortality regression lines are presented in Fig. 4.3.1.

Table: 4.3.2 Toxicity of endosulfan to larvae of the MR-, the FR- and the S- strains of *P. xylostella*

MR- strain			FR- strain			S-strain		
Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality
0.025	23.33	20.68	0.025	33.33	31.03	0.00625	17.78	17.78
0.05	36.66	34.47	0.05	40.00	37.93	0.0125	37.78	37.78
0.1	56.66	55.16	0.1	56.66	55.16	0.025	55.56	55.56
0.2	70.00	68.96	0.2	73.33	72.41	0.05	68.89	68.89
0.4	93.33	93.10	0.4	93.33	93.10	0.1	77.77	77.77
Control	3.33		Control	3.33		Control	0.00	

Results obtained from probit analysis:

χ^2 (3) = 1.032
(Not heterogeneous at P=0.05)
Slope (b) = 1.732 $\pm$ 0.281
Regression equation: y=1.732x + 1.679
LC_{50}=0.083
Fiducial limits of LC_{50} = 0.061-0.011

χ^2 (3) = 2.378
(Not heterogeneous at P=0.05)
Slope (b) = 1.476 $\pm$ 0.286
Regression equation: y=1.476x + 2.308
LC_{50}=0.067
Fiducial limits of LC_{50} = 0.046-0.096

χ^2 (3) = 1.220
(Not heterogeneous at P=0.05)
Slope (b) = 1.371$\pm$ 0.229
Regression equation: y=1.371x + 3.123
LC_{50}=0.023
Fiducial limits of LC_{50} = 0.017-0.032

The log (concentration)-probit mortality regression lines are presented in Fig. 4.3.2.

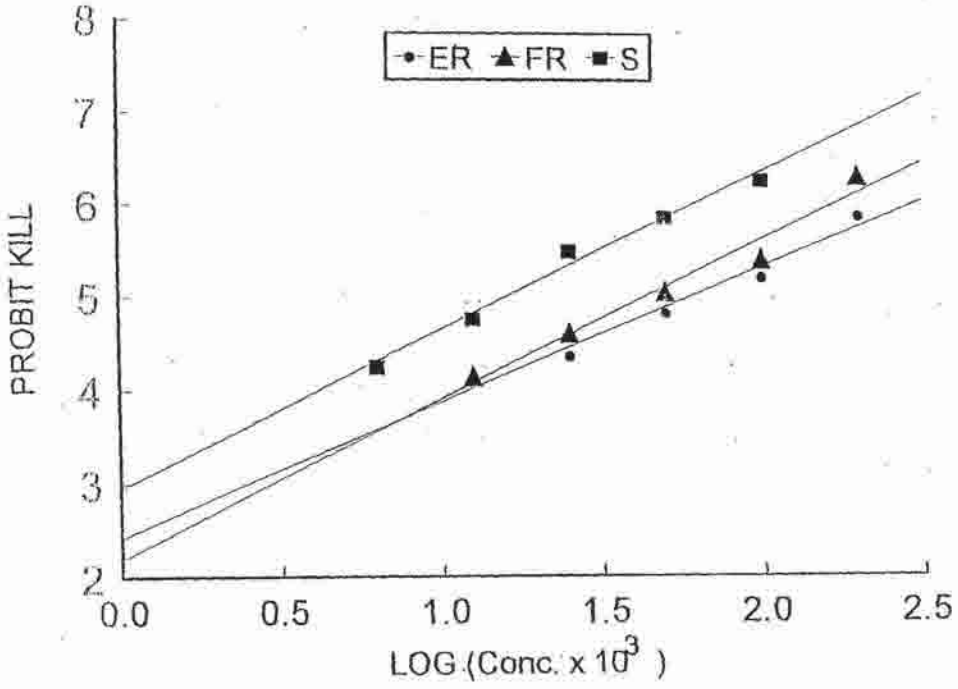


Fig. 4.3.1 : Log (Conc.) - Probit mortality regression lines for malathion to larvae of endosulfan (ER -), fenevalerate (FR -) resistant and susceptible (S -) strains

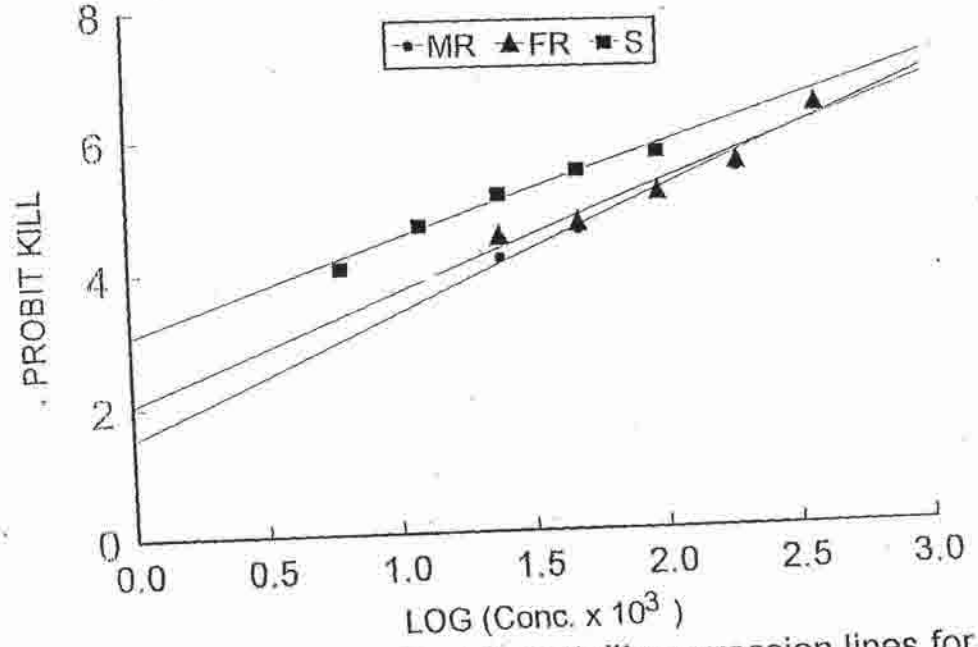


Fig. 4.3.2 : Log (Conc.) - Probit mortality regression lines for endosulfan to larvae of malathion (MR -), fenvalerate (FR -) resistant and susceptible (S -) strains

Table: 4.3.3 Toxicity of fenvalerate to larvae of the MR-, the FR- and the S- strains of *P. xylostella*

MR- strain			ER- strain			S-strain		
Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality
0.00312	17.11	13.94	0.00312	20.00	20.00	0.00625	13.33	13.33
0.00625	31.11	27.90	0.00625	46.66	46.66	0.0025	26.67	26.67
0.0125	51.11	48.83	0.0125	57.77	57.77	0.005	37.78	37.78
0.025	75.55	74.41	0.025	68.88	68.88	0.1	53.33	53.33
0.05	88.88	88.36	0.05	82.22	82.22	0.02	66.67	66.67
Control	4.44		Control	0.00		0.04	77.78	77.78
						Control	0.00	

Results obtained from probit analysis:

χ^2 (3) = 0.231
(Not heterogeneous at P=0.05)
Slope (b) = 1.931 $\pm$ 0.226
Regression equation: y=1.931x + 2.902
LC_{50}=0.01220
Fiducial limits of LC_{50} = 0.00981-0.01518

χ^2 (3) = 1.787
(Not heterogeneous at P=0.05)
Slope (b) = 1.339 $\pm$ 0.226
Regression equation: y=1.339x + 3.679
LC_{50}=0.00970
Fiducial limits of LC_{50} =0.007084-0.01328

χ^2 (3) = 0.654
(Not heterogeneous at P=0.05)
Slope (b) = 1.234 $\pm$ 0.169
Regression equation: y=1.234x + 4.069
LC_{50}=0.00567
Fiducial limits of LC_{50} = 0.00418-0.00769

The log (concentration)-probit mortality regression lines are presented in Fig. 4.3.3.

Table: 4.3.4 Toxicity of cypermethrin to larvae of the MR, the ER-, the FR- and the S- strains of *P. xylostella*

MR- strain			ER- strain			FR- strain			S- strain		
Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	FR- strain	FR- strain	FR- strain	Conc.	Per cent mortality	Per cent corrected mortality
0.00312	20.00	20.00	0.00312	23.33	23.33	Conc.	Conc.	Conc.	0.00312	33.33	25.92
0.00625	36.66	36.66	0.00625	40.00	40.00	0.00625	0.00625	0.00625	0.00625	46.66	40.73
0.0125	56.66	56.66	0.0125	63.33	63.33	0.0125	0.0125	0.0125	0.0125	70.00	66.66
0.025	63.33	63.33	0.025	73.33	73.33	0.025	0.025	0.025	0.025	76.66	74.06
0.05	86.66	86.66	0.05	93.33	93.33	0.05	0.05	0.05	0.05	93.33	92.58
Control	0.00		Control	0.00		0.1	0.1	0.1	Control	10.00	

Results obtained from probit analysis:

χ^2 (3) = 1.476
(Not heterogeneous at P=0.05)
Slope (b) = 1.492 $\pm$ 0.223
y=1.492x + 3.441
(Regression equation)
LC_{50}=0.01109
Fiducial limits of LC_{50} = 0.00843-0.01458

χ^2 (3) = 1.202
(Not heterogeneous at P=0.05)
Slope (b) = 1.716 $\pm$ 0.192
y=1.716x + 3.389
(Regression equation)
LC_{50}=0.00868
Fiducial limits of LC_{50} = 0.00692-0.01088

χ^2 (3) = 5.057
(Not heterogeneous at P=0.05)
Slope (b) = 1.759 $\pm$ 0.242
y=1.759x + 2.774
(Regression equation)
LC_{50}=0.01843
Fiducial limits of LC_{50} = 0.01443-0.02355

χ^2 (3) = 1.335
(Not heterogeneous at P=0.05)
Slope (b) = 1.639 $\pm$ 0.229
y=1.639x + 3.510
(Regression equation)
LC_{50}=0.00810
Fiducial limits of LC_{50} = 0.00610-0.01059

The log (concentration)-probit mortality regression lines are presented in Fig. 4.3.4.

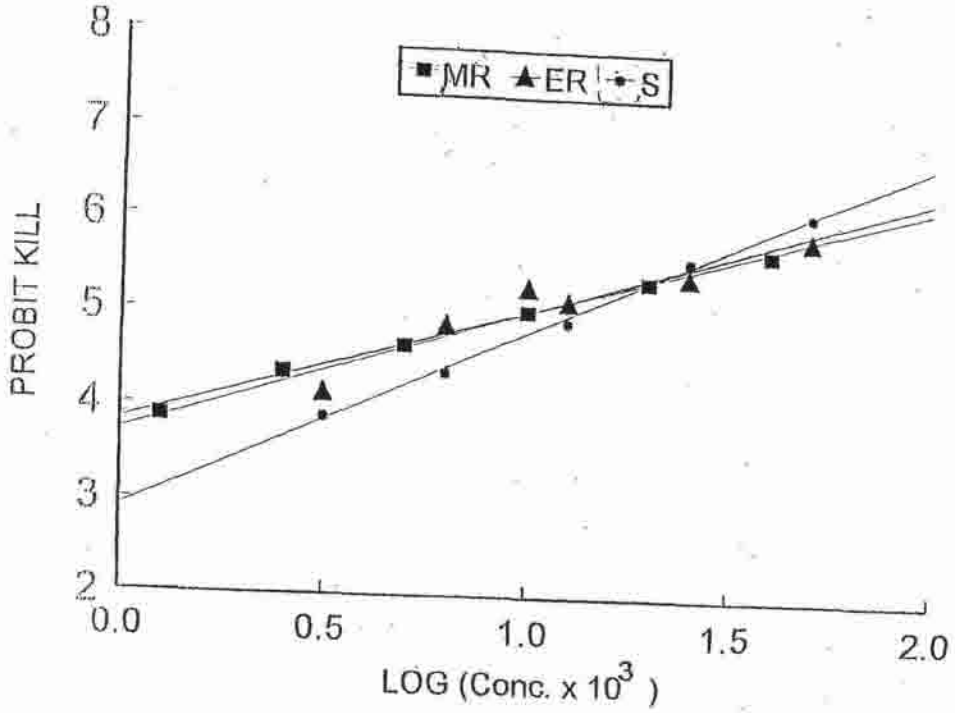


Fig. 4.3.3 : Log (Conc.) - Probit mortality regression lines for fenvalerate to larvae of malathion (MR -), the endosulfan (ER -) resistant and susceptible (S -) strains

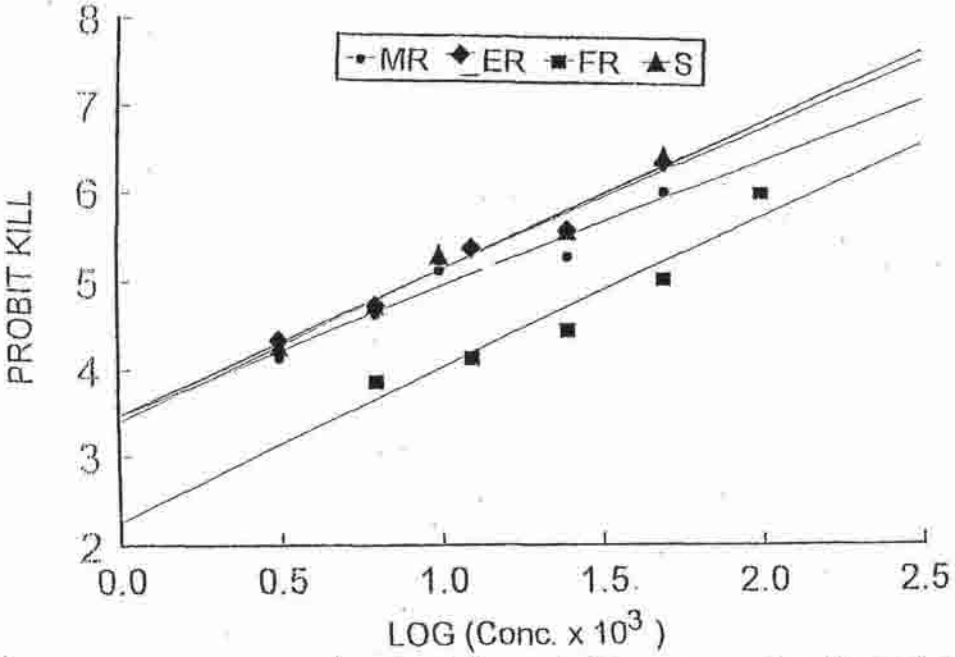


Fig. 4.3.4 : Log (Conc.) - Probit mortality regression lines for cypermethrin to larvae of malathion (MR -), the endosulfan (ER -) , fenvalerate (FR -) resistant and susceptible (S -) strains

Table: 4.3.5 Toxicity of Lambda-Cyhalothrin to larvae of the MR-,the ER-, the FR- and the S- strains of *P. xylostella*

MR- strain			ER- strain			FR- strain			S- strain		
Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality
0.00125	16.66	16.66	0.00125	22.22	18.60	0.00125	20.00	20.00	0.000625	20.00	14.29
0.0025	33.33	33.33	0.0025	40.00	37.21	0.0025	28.88	28.88	0.00125	30.00	25.00
0.005	53.33	53.33	0.005	60.00	58.14	0.005	53.33	53.33	0.0025	36.66	32.14
0.01	63.33	63.33	0.01	68.88	67.74	0.01	66.66	66.66	0.005	63.33	60.71
0.02	83.33	83.33	0.02	88.88	88.36	0.02	93.33	93.33	0.1	73.33	71.42
Control	0.00		Control	4.44		Control	0.00		0.02		96.42
									Control	6.66	

Results obtained from probit analysis:

χ^2 (3) = 0.725	χ^2 (3) = 1.586	χ^2 (4) = 1.603	χ^2 (3) = 2.888
(Not heterogeneous at P=0.05)	(Not heterogeneous at P=0.05)	(Not heterogeneous at P=0.05)	(Not heterogeneous at P=0.05)
Slope (b) = 1.522 $\pm$ 0.224	Slope (b) = 1.774 $\pm$ 0.278	Slope (b) = 1.501 $\pm$ 0.179	Slope (b) = 1.635 $\pm$ 0.223
y=1.522x + 2.410	y=1.774x + 2.062	y=1.501x + 2.590	y=1.635x + 2.471
(Regression equation)	(Regression equation)	(Regression equation)	(Regression equation)
LC_{50}=0.00502	LC_{50}=0.00453	LC_{50}=0.00403	LC_{50}=0.00351
Fiducial limits of LC_{50} = 0.003628-0.00696	Fiducial limits of LC_{50} = 0.00364-0.00564	Fiducial limits of LC_{50} = 0.00313-0.00520	Fiducial limits of LC_{50} = 0.00264-0.00471

The log (concentration)-probit mortality regression lines are presented in Fig. 4.3.5.

Table: 4.3.6 Toxicity of monocrotophos to larvae of the MR-, the ER-, the FR- and the S- strains of *P. xylostella*

MR- strain			ER- strain			FR- strain			S- strain		
Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality	Conc.	Per cent mortality	Per cent corrected mortality
0.00625	20.00	12.20	0.00625	13.33	13.33	0.00625	20.00	16.28	0.00625	15.55	15.55
0.0125	24.44	17.07	0.0125	22.22	22.22	0.0125	28.88	25.57	0.0125	28.88	28.88
0.025	37.77	31.70	0.025	33.333	33.333	0.025	40.00	37.21	0.025	42.22	42.22
0.05	62.22	58.53	0.05	60.00	60.00	0.05	66.66	65.11	0.05	71.11	71.11
0.1	84.44	82.92	0.1	84.44	84.44	0.1	88.88	88.36	0.1	91.11	91.11
0.2	91.11	90.24	Control	0.00		Control	4.44		Control	0.00	
Control	8.88										

Results obtained from probit analysis:

χ^2 (3) = 6.443
(Not heterogeneous at P=0.05)
Slope (b) = 1.511 ± 0.194
y=1.511x + 2.481
(Regression equation)
LC_{50}=0.046
Fiducial limits of LC_{50} = 0.03551-0.06074

χ^2 (3) = 2.894
(Not heterogeneous at P=0.05)
Slope (b) = 1.877 ± 0.227
y=1.877x + 2.605
(Regression equation)
LC_{50}=0.024
Fiducial limits of LC_{50} = 0.02289-0.03641

χ^2 (3) = 8.408
(Not heterogeneous at P=0.05)
Slope (b) = 2.007 ± 0.241
y=2.007x + 2.101
(Regression equation)
LC_{50}=0.029
Fiducial limits of LC_{50} = 0.02252-0.03437

χ^2 (3) = 1.920
(Not heterogeneous at P=0.05)
Slope (b) = 1.987 ± 0.234
y=1.987x + 2.333
(Regression equation)
LC_{50}=0.020
Fiducial limits of LC_{50} = 0.01614-0.02815

The log (concentration)-probit mortality regression lines are presented in Fig. 4.3.6.

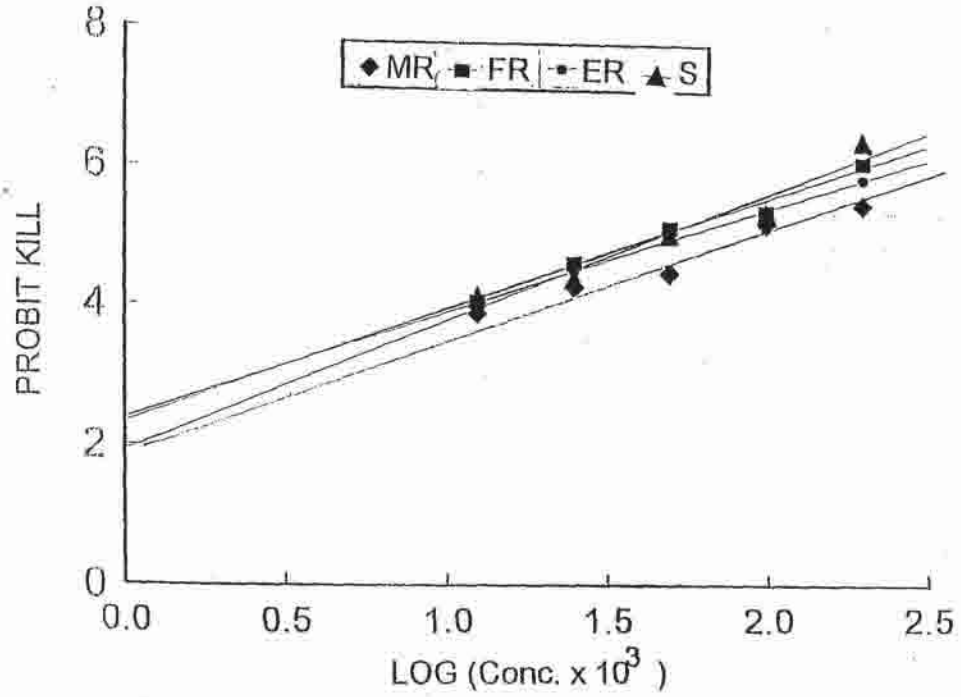


Fig. 4.3.5: Log (Conc.) - Probit mortality regression lines for lambda-cyhalothrin to larvae of malathion (MR -), the fenevalerate (FR -), the endosulfan (ER -) resistant and susceptible (S -) strains

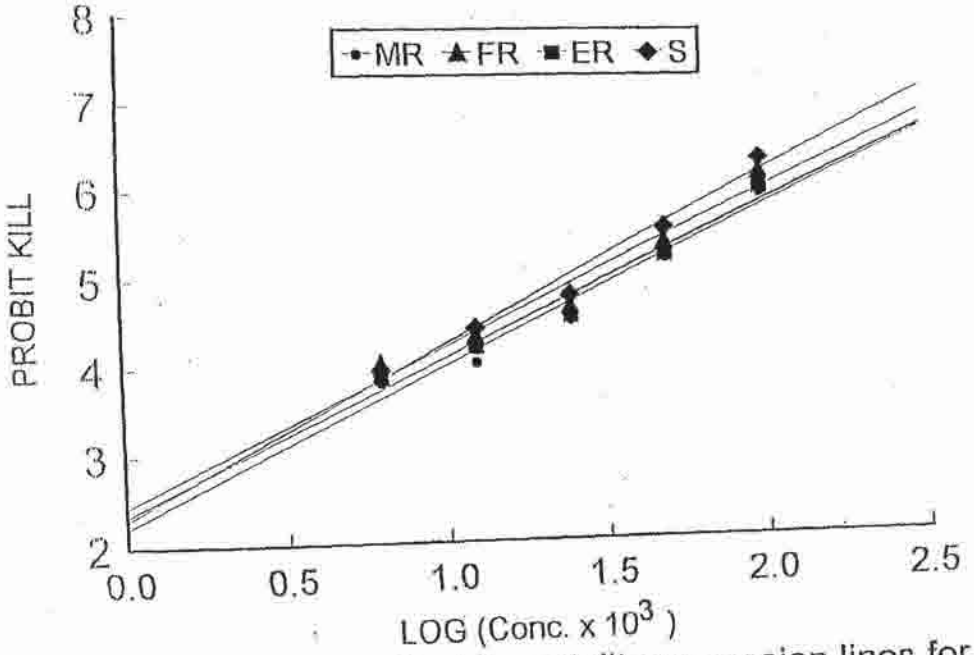


Fig. 4.3.6 : Log (Conc.) - Probit mortality regression lines for monocrotophos to larvae of malathion (MR -), the fenvalerate (FR -), endosulfan (ER -) resistant and susceptible (S -) strains

Table: 4.3.7 Comparative toxicity of various insecticides to the larvae of susceptible and resistant strains of P. xylostella

Insecticide	Strain	Heterogeneity	Regression equation (y=)	Slope (b)	LC_{50} (%)	Fiducial limits of LC_{50} (%)	Resistance ratio (R/S)
Malathion	MR	χ^2 (3) = 3.471	2.682x - 0.169	2.682 ± 0.398	0.847	0.724-0.990	27.32
	ER	χ^2 (3)=1.187	1.402x + 2.417	1.402 ± 0.022	0.070	0.046-0.078	2.26
	FR	χ^2 (3)=1.487	1.650x + 2.169	1.650 ± 0.229	0.052	0.034-0.055	1.68
	S	χ^2 (3) =0.788	1.754x + 2.382	1.754 ± 0.235	0.031	0.024-0.040	
Endosulfan	MR	χ^2 (3)=1.032	1.732x + 1.679	1.732 ± 0.281	0.083	0.061-0.11	3.61
	ER	χ^2 (3)=3.763	2.908x - 0.347	2.908 ± 0.455	0.689	0.596 - 0.799	29.96
	FR	χ^2 (3)=2.378	1.476x + 2.308	1.476 ± 0.2857	0.067	0.046-0.096	2.91
	S	χ^2 (3)=1.220	1.371x + 3.123	1.371 ± 0.229	0.023	0.017 - 0.032	
Fenvalerate	MR	χ^2 (3)=0.231	1.931x + 2.902	1.931 ± 0.226	0.01220	0.00981-0.01518	2.15
	ER	χ^2 (3)=1.787	1.339x + 3.679	1.339 ± 0.226	0.00970	0.007084-0.01328	1.71
	FR	χ^2 (3)=0.443	2.002x + 2.964	2.002 ± 0.251	0.10409	0.08382 - 0.12925	19.06
	S	χ^2 (4)=0.654	1.234x + 4.069	1.234 ± 0.169	0.00567	0.00418 - 0.00769	
Monocrotophos	MR	χ^2 (3)=6.443	1.511x + 2.481	1.511 ± 0.194	0.046	0.03551-0.06074	2.30
	ER	χ^2 (3)=8.408	2.007x + 2.101	2.007 ± 0.2414	0.029	0.02252-0.03437	1.38
	FR	χ^2 (3)=2.894	1.877x + 2.605	1.877± 0.227	0.024	0.02289-0.03641	1.15
	S	χ^2 (3)=1.920	1.987x + 2.333	1.987 ± 0.234	0.020	0.01614-0.02815	
Cypermethrin	MR	χ^2 (3)=1.476	1.492x + 3.441	1.492 ± 0.223	0.01109	0.00843-0.01458	1.37
	ER	χ^2 (3)=1.202	1.716x + 3.389	1.716 ± 0.192	0.00868	0.00692-0.01088	1.07
	FR	χ^2 (3)=5.057	1.759x + 2.774	1.759 ± 0.242	0.01843	0.01443-0.02355	2.28
	S	χ^2 (3)=1.335	1.639x + 3.510	1.639 ± 0.229	0.00810	0.00610-0.01059	
Lambda-Cyhalothrin	MR	χ^2 (3)=0.725	1.522x + 2.410	1.522 ± 0.224	0.00502	0.003628-0.00696	1.43
	ER	χ^2 (4)=1.603	1.501x + 2.590	1.501 ± 0.179	0.00403	0.00313-0.00520	1.15
	FR	χ^2 (3)=1.586	1.774x + 2.062	1.774 ± 0.278	0.00453	0.00364-0.00564	1.29
	S	χ^2 (4)=2.888	1.635x + 2.471	1.635 ± 0.223	0.00351	0.00264-0.00471	

MR = Malathion-resistant
ER = Endosulfan-resistant
FR = Fenvalerate-resistant
S = Susceptible

4.4 Comparative biological characteristic of resistant strains of *P. xylostella*

The biology of resistant strains of *P. xylostella* was studied under laboratory condition at 28 ± 1^{0}C. The duration of egg, larval and pupal stages, per cent survival of the egg, larvae and pupae; duration of pre-oviposition and oviposition periods, and fecundity of susceptible and resistant strains were studied. Results in detail (Tables 4.4.1 to 4.4.2) are given below:

4.4.1 Incubation period:

Average incubation period was significantly longer for the resistant strains than the susceptible strain (2.79 days). Among the resistant strain, fenvalerate- resistant strain had significantly longer incubation period (3.83 days) than the endosulfan- resistant strain (3.29 days) but did not differ significantly from malathion- resistant strain (3.54 days) (Table 4.4.1). Malathion-resistant and endosulfan- resistant strains were at par with each other for the duration of incubation period. Incubation period varied from 2 to 6 days for resistant strains and 2 to 4 days for susceptible strain. Average egg survival of FR, ER, MR and S strains was 88.00, 88.00, 92.00 and 93.20 per cent, respectively. However, there were no significant differences among these strains for per cent egg survival.

4.4.2 Larval period:

The average larval period of the susceptible strain was significantly longer (8.19 days) than the three resistant strains viz., malathion - resistant (6.74 days), endosulfan – resistant (7.27 days) and fenvalerate – resistant (6.53 days). The three resistant strains did not differ significantly from one another for the duration of larval stage. Duration of larval stage of different strains varied from 5 to 10 days (Table 4.4.1). Larval survival was 93.00, 89.00, 85.33 and 83.00 per cent in susceptible, malathion – resistant, endosulfan – resistant and

fenvalerate resistant strains, respectively. There were no significant differences among different strains for larval survival

4.4.3 Pupal period:

The pupal period of the susceptible strain varied from 3-6 days with an average of 4.52 days. Pupal period of malathion-, endosulfan- and fenvalerate-resistant strains varied from 3-5 days with averages of 3.94, 3.84 and 3.58 days, respectively (Table 4.4.1). Duration of pupal stage was significantly longer in susceptible strain as compared to resistant – strains. The resistant- strains were on par with one another for duration of pupal stage. The average pupal survival of the susceptible, the malathion-, endosulfan- and fenvalerate- resistant strains was 91.00, 87.00, 92.00 and 87.00 per cent, respectively. The per cent survival of pupal period was found non- significant.

4.4.4 Total development period:

The total developmental period of the susceptible, the malathion-resistant, endosulfan-resistant and fenvalerate-resistant strains varied from 11 to 18, 10 to 17, 12 to 18 and 12 to 16 days, respectively with corresponding averages of 15.76, 14.25, 14.48 and 13.74 days (Table 4.4.1). Data showed that the susceptible strain had significantly longer developmental period than the resistant strains.

4.4.5 Pre-oviposition period:

Pre-oviposition period of the susceptible strain varied from 1-5 days and in malathion-resistant, endosulfan-resistant and fenvalerate strains, it varied from 2-5 days. The average pre-oviposition period of the susceptible, the malathion-resistant, endosulfan-resistant and fenvalerate-resistant strains was 2.5, 2.9, 2.8 and 3.3 days, respectively and the four strains did not significantly from one another for pre- oviposition period. (Table 4.4.2).

Table: 4.4.1 Duration and survival of different life stages of malathion -, endosulfan-, fenvalerate – resistant and susceptible strains of *P. xylostella*

Strain	Egg stage		Larval stage		Pupal stage		Total development period (days)
	Incubation period (days)	Survival (%)	Larval period (days)	Survival (%)	Pupal period (days)	Survival (%)	
Susceptible (S)	2.79± 0.18 (2-4)	93.20 ±5.31 (84-100)	8.19± 0.64 (5-10)	93.00± 5.10 (85-100)	4.52± 0.22 (3-6)	91.00 ±5.83 (80-95)	15.76 + 0.80 (11-18)
Malathion - resistant (MR)	3.54± 0.09 (2-5)	92.00 ±5.66 (82-98)	6.74 ±0.17 (5-9)	89.00 ±6.63 (80-100)	3.94 ±0.13 (3-5)	87.00 ±5.10 (80-95)	14.25 + 0.19 (10-17)
Endosulfan - resistant (ER)	3.29± 0.23 (2-5)	88.00 ±9.27 (80-100)	7.27± 0.45 (5-10)	85.33 ±11.47 (66.67-100)	3.84± 0.46 (3-5)	92.00 ±5.10 (85-95)	14.48 + 0.37 (12-18)
Fenvalerate - resistant (FR)	3.83± 0.29 (3-6)	88.00± 6.07 (80-96)	6.53± 0.45 (5-8)	83.00± 8.12 (80-95)	3.58 ±0.26 (3-5)	87.00 ±10.77 (80-100)	13.74 + 0.22 (12-16)
CD (0.05)	0.32	NS	0.75	NS	0.47	NS	0.70

Figures in parentheses represent the range

Table: 4.4.2 Pre-oviposition period, oviposition period and fecundity of malathion-, endosulfan- and fenvalerate- resistant and susceptible strain of *P. xylostella*

Strain	Pre-oviposition period (days)	Oviposition period (days)	Fecundity (Number of eggs laid per female)
Susceptible (S)	2.5 ± 1.03 (1-5)	6.6± 0.08 (6-8)	194.10 ± 50.33 (110-284)
Malathion - resistant (MR)	2.9 ± 1.04 (2-5)	6.2 ± 1.17 (5-8)	198.40 ± 45.40 (140-268)
Endosulfan - resistant (ER)	2.8 ± 1.04 (2-5)	6.5 ± 1.03 (5-8)	202.30± 42.61 (120-275)
Fenvalerate - resistant (FR)	3.3 ± 1.10 (2-5)	5.9 ± 1.37 (4-8)	211.00 ± 44.10 (127-296)
CD (0.05)	NS	NS	NS

Figures in parentheses represent the range

4.4.6 Oviposition period:

Oviposition period varied form 6-8 days for susceptible strain and 4-8 days for fenvalerate-resistant strain where as, 5-8 days both for malathion-resistant and endosulfan-resistant strains (Table 4.4.2). The average oviposition period of susceptible, the malathion-resistant, endosulfan-resistant and fenvalerate-resistant strains was 6.6, 6.2, 6.5 and 5.9 days, respectively and the strains were at par with one another for oviposition period.

4.4.7 Fecundity:

Average number of eggs laid per female was found to be 194.10, 198.40, 202.30, and 211.00 in the susceptible, malathion-resistant, endosulfan-resistant and fenvalerate-resistant strains with a range of 110-284, 140-268, 120-275 and 127-296, respectively. No significant differences were observed among these strains for fecundity.

Data presented in Table 4.4.1 to 4.4.2 showed that the resistant strains had become biologically superior by having shorter developmental period and with no adverse affect on the fecundity and survival of eggs, larvae and pupae.

DISCUSSION

Chapter-v

DISCUSSION

The results of the investigation entitled "Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)" are discussed under the following heads:

5.1 Status of resistance to malathion, endosulfan and fenvalerate in *P. xylostella* in Himachal Pradesh.

5.2 Selection for resistance to malathion, endosulfan and fenvalerate in *P. xylostella.*

5.3 Cross – resistance pattern of resistant strains of *P. xylostella.*

5.4 Biological characteristics of resistant strains of *P. xylostella.*

5.1 Status of resistance to malathion, endosulfan and fenvalerate in *P. xylostella* in Himachal Pradesh

In the present investigation, malathion, endosulfan and fenvalerate have been tested for their toxicity against the 3rd instar larval stage of different populations of *P. xylostella* collected from agroclimatically different vegetable growing areas of Himachal Pradesh. The results have been presented in Tables 4.1.1 to 4.1.39 and summarised in Tables 5.1.1 to 5.1.3 are discussed below:

5.1.1 Toxicity of malathion to larvae of *P. xylostella*

The toxicity data of malathion to 3rd instar larvae of the *P. xylostella* have been given in Tables 4.1.1 to 4.1.13 and summarized in the Table 5.1.1.

Data (Table 5.1.1) showed that the LC_{50} values of malathion against 3rd instar larvae varied from 0.0231 to 0.0491 per cent. The lowest LC_{50} value (0.0231 %) of malathion was

Table: 5.1.1 Toxicity of malathion to larvae of different populations of *P. xylostella* collected from different vegetable growing localities of Himachal Pradesh

District	Location	LC_{50} (%)	Fiducial limits of LC_{50} (%)	Regression equation (y=)	Slope (b)	Heterogeneity	LC_{99} (%)	Relative toxicity RT	RR
Kullu	Kalheli	0.0447	0.0346 - 0.0578	1.729x + 2.147	1.729 ± 0.251	$\chi^2(3) = 2.417$	0.990	1.935	19.80
	Garasa	0.0356	0.0278 - 0.0457	1.773x + 2.247	1.773 ± 0.242	$\chi^2(4) = 0.716$	0.732	1.541	14.64
	Hurla	0.0440	0.0343 - 0.0565	1.654x + 2.281	1.654 ± 0.226	$\chi^2(3) = 2.787$	1.123	1.905	22.46
Mandi	Chailchock	0.0399	0.0313 - 0.0509	1.619x + 2.407	1.619 ± 0.192	$\chi^2(3) = 1.320$	1.093	1.727	21.86
	Balh area	0.0443	0.0346 - 0.0568	1.715x + 2.176	1.715 ± 0.237	$\chi^2(3) = 0.237$	1.008	1.918	20.16
Una	Rampur	0.0329	0.0294 - 0.0503	1.585x +2.594	1.585 ± 0.221	$\chi^2(3) = 3.171$	0.968	1.424	19.36
	Santokhgarh	0.0376	0.0297 - 0.0476	1.844x + 2.096	1.844 ± 0.243	$\chi^2(3) = 3.255$	0.686	1.628	13.72
Hamirpur	Nadaun	0.0269	0.0207 - 0.0350	1.564x + 2.762	1.564 ± 0.227	$\chi^2(3) = 1.386$	0.827	1.165	16.54
Kangra	Jamanabad	0.0334	0.0271 - 0.0473	1.688x + 2.429	1.688 ± 0.234	$\chi^2(3) = 1.258$	0.797	1.446	15.94
	Samloti	0.0231	0.0173 - 0.0389	1.515x + 2.934	1.515 ± 0.260	$\chi^2(3) = 1.928$	0.793	1.000	15.86
Shimla	Theog	0.0425	0.0324 – 0.0558	1.578x + 2.430	1.578± 0.246	$\chi^2(3) = 1.338$	1.267	1.840	25.34
	Matyana	0.0364	0.0270 - 0.0483	1.548x + 2.584	1.548 ± 0.253	$\chi^2(3) = 0.526$	1.157	1.576	23.15
	Sandhu	0.0491	0.0320 - 0.0642	1.574x + 2.334	1.574 ± 0.173	$\chi^2(3) = 0.437$	1.486	2.126	29.72
	Average	0.0377	-	-	-	-	0.994	-	19.89

RT= Relative toxicity, RR= Resistance ratio

obtained for the population collected from Samloti (Kangra district) and the highest (0.0491%) for the populations from Sandhu (Shimla district). When compared with LC_{50} value for population from Samloti (0.0231 %), malathiion was 1.165 to 2.126 times less toxic to larvae of the populations collected from other areas of the state. However, the fiducial limits of the LC_{50} values of malathion calculated for the larvae of different populations overlapped, which revealed that different populations did not differ statistically with one another for their susceptibility to malathion. LC_{50} values obtained in the present finding are very close to those reported by Verma and Sandhu (1967) and Verma *et al.* (1972) who found LC_{50} values of malathion to be 0.0102 and 0.00702 per cent, respectively against 4th instar larvae of *P. xylostella*. Contrary to the present results, Chawla and Kalra (1976) reported very high LC_{50} (>0.5 %) of malathion against 3rd instar larvae of *P. xylostella* collected from Ludhiana, Jullundhar and Amritsar by using direct spray method of bioassay. The difference in the LC_{50} value of malathion obtained by Chawla and Kalra (1976) might be due to difference in the susceptibility level of the populations of *P. xylostella*. The populations tested by these workers appear to be comparatively less susceptible and highly resistant to malathion.

5.1.2 Toxicity of endosulfan to larvae of *P. xylostella*

Toxicity data for endosulfan against 3rd instar larvae of *P. xylostella* have been presented in Tables 4.1.14 to 4.1.26 and summarized in Table 5.1.2.

Data (Table 5.1.2) showed that LC_{50} values of endosulfan against 3rd instar larvae varied form 0.0252 to 0.0386 per cent. The lowest LC_{50} value of endosulfan (0.0252%) has been obtained for the population collected from Nadaun (Hamirpur district) and highest (0.0386%) for the population from Kalheli (Kullu district). In comparison to LC_{50} value for

Table: 5.1.2 Toxicity of endosulfan to larvae of different populations of *P. xylostella* collected from different vegetable growing localities of Himachal Pradesh

District	Location	LC_{50} (%)	Fiducial limits of LC_{50} (%)	Regression equation (y=)	Slope (b)	Heterogeneity	LC_{99} (%)	Relative toxicity	RR
Kullu	Kalheli	0.0386	0.0306 - 0.0487	1.686x + 2.324	1.686 ± 0.188	$\chi^2(4) = 5.210$	0.928	1.532	18.56
	Garasa	0.0276	0.0216 - 0.0354	1.659x + 2.608	1.659 ± 0.227	$\chi^2(3) = 1.947$	0.698	1.095	13.96
	Hurla	0.0349	0.0279 - 0.0437	1.704x + 2.370	1.704 ± 0.179	$\chi^2(4) = 3.005$	0.810	1.385	16.20
Mandi	Chailchock	0.0333	0.0262 - 0.0423	1.656x + 2.477	1.656 ± 0.194	$\chi^2(4) = 2.281$	0.848	1.321	16.96
	Balh area	0.0309	0.0233 - 0.0409	1.551x + 2.689	1.551 ± 0.257	$\chi^2(3) = 3.538$	0.977	1.226	19.54
Una	Rampur	0.0254	0.0199 - 0.0320	1.683x + 2.636	1.683 ± 0.227	$\chi^2(3) = 0.405$	0.612	1.008	12.24
	Santokhgarh	0.0279	0.0211 - 0.0368	1.548x + 2.763	1.548 ± 0.249	$\chi^2(3) = 1.602$	0.887	1.107	17.74
Hamirpur	Nadaun	0.0252	0.0203 - 0.0310	1.959x + 2.254	1.959 ± 0.241	$\chi^2(3) = 1.579$	0.388	1.000	07.76
Kangra	Jamanabad	0.0290	0.0227 - 0.0373	1.857x + 2.282	1.857 ± 0.783	$\chi^2(3) = 0.142$	0.520	1.151	10.40
	Samloti	0.0261	0.0189 - 0.0358	1.923x + 2.275	1.923 ± 0.321	$\chi^2(3) = 0.011$	0.423	1.036	08.45
Shimla	Theog	0.0347	0.0262 - 0.0450	1.696x + 2.384	1.696 ± 0.201	$\chi^2(3) = 3.563$	0.821	1.377	16.42
	Matyana	0.0336	0.0260 - 0.0431	1.555x + 2.626	1.555 ± 0.200	$\chi^2(4) = 5.203$	1.054	1.333	21.08
	Sandhu	0.0352	0.0270 - 0.0454	1.697x + 2.375	1.697 ± 0.232	$\chi^2(3) = 0.766$	0.827	1.397	16.54
	Average	0.0310	-	-	-	-	0.782	-	15.07

RT= Relative toxicity, RR= Resistance ratio

Nadaun population, endosulfan was 1.008 to 1.532 times less toxic to larvae of *P. xylostella* collected from different areas of the state. However, the differences in the LC_{50} values of endosulfan for different populations are not statistically significant showing thereby that populations collected from different localities of the state did not differ significantly with one another for their susceptibility to endosulfan. Results on the LC_{50} values obtained in the present study are in close conformity to those reported by Raju and Singh (1995) who found LC_{50} value of endosulfan for 2nd instar larvae of *P. xylostella* to be 0.036 and 0.028 per cent for the populations collected from two localities in Varanasi district of Utter Pradesh. Contrary to present findings, Verma *et al.* (1972) reported higher LC_{50} (0.127 %) of endosulfan against 4th instar larvae of *P. xylostella.* This difference can be attributed to comparatively less sensitivity of *P. xylostella* larvae used by Verma *et al.* (1972) for determining toxicity of endosulfan at Hisar.

5.1.3 Toxicity of fenvalerate to larvae of *P. xylostella*

Toxicity of fenvalerate to 3rd instar larvae of different populations of *P. xylostella* have been presented in Tables 4.1.27 to 4.1.39 and summarized in Table 5.1.3

The LC_{50} value of fenvalerate against 3rd instar larvae varied from 0.00708 % (Nadaun population) to 0.01070 % (Balh population). In comparison to LC_{50} for Nadaun population, fenvalerate was 1.055 to 1.511 times less toxic to populations from other areas. Comparatively higher susceptibility of Nadaun population can be attributed to less use of this insecticide in this area. Population collected from Balh area was comparatively less susceptible to fenvalerate (not different statistically from other populations). It can be due to higher usage of this insecticide or other synthetic pyrethroids in this area. Present findings on the LC_{50} values of fenvalerate to different populations of *P. xylostella* are in close conformity with Chawla and

Table: 5.1.3 Toxicity of fenvalerate to larvae of different populations of *P. xylostella* collected from different vegetable growing localities of Himachal Pradesh

District	Location	LC_{50} (%)	Fiducial limits of LC_{50} (%)	Regression equation (y=)	Slope (b)	Heterogeneity	LC_{99} (%)	Relative toxicity	RR
Kullu	Kalheli	0.00972	0.00758 - 0.01247	1.653x + 3.367	1.653 ± 0.229	$\chi^2(3) = 0.659$	0.248	1.373	24.80
	Garasa	0.00794	0.00612 - 0.01033	1.591x + 3.568	1.591 ± 0.223	$\chi^2(3) = 1.002$	0.231	1.121	23.10
	Hurla	0.00901	0.00699 - 0.01161	1.631x + 3.443	1.631 ± 0.229	$\chi^2(3) = 0.581$	0.241	1.273	24.10
Mandi	Chailchock	0.00752	0.00579 - 0.00978	1.625x + 3.575	1.625 ± 0.230	$\chi^2(3) = 1.608$	0.203	1.062	20.30
	Balh area	0.01070	0.00834 - 0.01375	1.648x + 3.303	1.648 ± 0.230	$\chi^2(3) = 0.779$	0.276	1.511	27.60
Una	Rampur	0.00875	0.00675 - 0.01134	1.706x + 3.393	1.706 ± 0.303	$\chi^2(2) = 1.888$	0.202	1.236	20.20
	Santokhgarh	0.00969	0.00724 - 0.01299	1.479x + 3.539	1.479 ± 0.233	$\chi^2(3) = 2.066$	0.362	1.369	36.20
Hamirpur	Nadaun	0.00708	0.00458 - 0.01094	1.460x + 3.758	1.460 ± 0.179	$\chi^2(3) = 1.697$	0.278	1.000	27.80
Kangra	Jamanabad	0.00747	0.00482 - 0.01159	1.497x + 3.692	1.497 ± 0.188	$\chi^2(4) = 3.091$	0.267	1.055	26.70
	Samloti	0.00783	0.00587 - 0.01045	1.524x + 3.638	1.524 ± 0.261	$\chi^2(3) = 3.356$	0.263	1.106	26.30
Shimla	Theog	0.00983	0.00751 - 0.01280	1.587x + 3.425	1.587 ± 0.238	$\chi^2(3) = 0.348$	0.287	1.388	28.73
	Matyana	0.00899	0.00677 - 0.01196	1.577x + 3.495	1.577 ± 0.262	$\chi^2(3) = 0.119$	0.269	1.270	26.90
	Sandhu	0.00996	0.00760 - 0.01305	1.558x + 3.445	1.558 ± 0.234	$\chi^2(3) = 0.794$	0.310	1.407	31.00
	Average	0.00807	-	-	-	-	0.264	-	26.44

RT= Relative toxicity, RR= Resistance ratio

Joia (1991), who reported LC_{50} value of fenvalerate to be 0.0088 and 0.011 per cent for 3rd instar larvae (measuring 0.5 cm and having average weight of 2 mg/ larva) of the populations collected from Ludhiana and Jalandhar, respectively during 1988-89.

Contrary to present findings, Raju and Singh (1995) reported LC_{50} values of fenvalerate to be 0.00367 and 0.00345 per cent against 2nd instar larvae of populations collected from two different locations in Varanasi district of Utter Pradesh. These values are much lower as compared to LC_{50} values computed in the present study. The difference might be due to prevalence of comparatively more susceptible strains of the insect in area. The difference in the LC_{50} values could also be due to the difference in the larval stage of the insect used for testing toxicity (3rd instar larvae used in the present study as compared to 2nd instar larvae used by Raju and Singh, 1995) because the age of the test insect can influence the toxicity of insecticide (Busvine, 1971). Generally, earlier instars of insects are more susceptible to insecticides than later instars.

Joia and Udeaan (1998) obtained very high LC_{50} values of 1.6, 1.8, 1.4, 1.1 and 0.8 per cent of fenvalerate for populations of *P. xylostella* collected from Jalandhar, Phagwara, Mansa, Patiala and Samrala, respectively. These high values might be due to difference in the bioassay method used for assessing toxicity. Joia and Udeaan (1998) used leaf disc method as compared to direct spray method used in the present study.

Results on the toxicity of malathion, endosulfan and fenvalerate to 3rd instar larvae of *P. xylostella* also showed that on the average LC_{50} values of the respective insecticides were 0.0377, 0.0310 and 0.00807 per cent. Since base line toxicity data for these insecticides against *P. xylostella* in Himachal Pradesh are lacking, therefore LC_{50} values obtained in the

present studies can be used as base line data for future comparisons to monitor any change in the susceptibility of *P. xylostella* to said insecticides in the state.

5.1.4 Assessment of resistance:

Data presented in Tables 5.1.1 to 5.1.3 indicate that on the basis of LC_{50} values, the larvae of the populations collected from different locations of the state do not differ statistically among themselves for their susceptibility to malathion, endosulfan and fenvalerate. Extensive use of test insecticides on vegetable crops has made exceedingly difficult to find a truly susceptible population of *P. xylostella*. Further in the absence of the base- line toxicity data for malathion, endosulfan and fenvalerate against *P. xylostella* in Himachal Predesh, it is not possible to authenticate the levels of tolerance/ resistance that this insect has developed to these insecticides. In order to obtain an index of resistance level, resistance ratios for different populations have been worked out as per method given by Saxena *et al.* (1989). Accordingly, LC_{99} values of malathion, endosulfan and fenvalerate for the larvae (3^{rd} instar) of *P. xylostella* were divided with the field recommended concentrations of these insecticides (0.05% for both malathion and endosulfan, and 0.01% for fenvalerate).

Malathion: Data presented in Tables 4.1.1 to 4.1.13 and summarised in Table 5.1.1 showed that lowest LC_{99} value (0.686 %) of malathion was calculated for Santokhgarh population with 13.72 times resistance ratio while highest LC_{99} value (1.486 %) was calculated for Sandhu population (29.72 times resistance ratio) (Table 5.1.1). For other populations, LC_{99} value of malathion has varied from 0.732 to 1.267 per cent with 14.64 to 25.34 times resistance ratios. On the average, *P. xylostella* has shown 19.89-fold resistance to malathion.

Endosulfan: Data presented in the Table 4.1.14 to 4.1.26 and summarised in Table 5.1.2 showed that LC_{99} values of endosulfan for third instar larvae of different populations varied

from 0.388 per cent to Nadaun population (7.76- fold resistance ratio) to 1.054 per cent to Matyana population (21.08- fold resistance ratio). On the average, resistance ratio of endosulfan for *P. xylostella* is 15.07 times.

Fenvalerate: Data presented in Tables 4.1.27 to 4.1.39 and summarised in Table 5.1.3 showed that LC_{99} values of fenvalerate for different populations of *P. xylostella* have varied from 0.202 % to Rampur population to 0.362 % to Santokhgarh population. Populations from respective areas have been found to develop 20.20 and 36.20 times resistance to fenvalerate. On the average, *P. xylostella* has been found to develop 26.44 times resistance to fenvalerate.

Data (Tables 5.1.1 to 5.1.3) show that resistance ratios for malathion, endosulfan and fenvalerate to different populations of *P. xylostella* have varied from 13.72 to 29.72 times, 7.76 to 21.08 times and 20.20 to 36.20 times, respectively. The average resistance ratios for thirteen populations have been worked out to be 19.89, 15.07 and 26.44 for malathion, endosulfan and fenvalerate, respectively. In general, resistance ratios for fenvalerate are higher as compared to two other insecticides and this can be due to over reliance of farmer on synthetic pyrethroids including fenvalerate for the control of *P. xylostella* on cole vegetable crops.

On the basis of resistance ratios, it can be concluded that *P. xylostella* has developed moderate degree of resistance to malathion, endosulfan and fenvalerate in all the thirteen localities of the state although levels of resistance varied from locality to locality. These results are not unexpected because malathion, endosulfan and fenvalerate are being extensively used in Himachal Pradesh for the control of lepidopterous insect-pest including of *P. xylostella* on cabbage and cauliflower crops for more than two decades. Thus, there are

more chances of this insect to become tolerant/ resistant to these insecticides by coming in their contact (directly or indirectly).

Although, there is no report on the development of resistance to malathion, endosulfan and fenvalerate in *P. xylostella* from Himachal Pradesh, yet high levels of resistance to these insecticides in this pest have been reported from different parts of world. Sudderuddin and Kok (1978) reported 2096 times resistance to malathion in Malaysia. Similarly, Barroga *et al.* (1981) reported 305- and 735- fold resistance to malathion in Laguna and Manila (Trinidad). Joia and Udeaan (1998) reported high level of resistance (40 to 128 times) to quinalphos (a related organophosphate insecticide) in populations of DBM collected from various locations of Punjab. Yu and Nguyan (1992) reported that there were 20 to 73-fold resistance to organophosphates (chlorpyrifos, methyl parathion, malathion, methamidophos and diazinon). Lee and Lee (1979) found very high levels of resistance to endosulfan in strains of *P. xylostella* collected from various vegetable growing areas in Taiwan. High levels of resistance endosulfan (25-fold) have also been reported from North Florida (Yu and Nguyan, 1992).

High level of resistance to fenvalerate in diamondback moth has been reported by Saxena *et al.* (1989) in populations collected from Ranchi (178.00 times), Jaunpur (80.23 times), Panipat (143.20 times) and Delhi (43.37 times). Resistance to four major synthetic pyrethroids viz, permethrin, cypermethrin, deltamethrin and fenvalerate in most field strains of diamondback moth has been reported from Taiwan (Liu *et al.*, 1981, 1982; Cheng, 1981; Cheng *et al.*, 1985). Various Japanese populations of *P. xylostella* have also shown high degree of resistance to fenvalerate (Hama, 1988). Strain of this insect collected from cabbage in North Florida also showed high resistance to pyrethroids (ranged from 2132- to 82475-fold) and was highest to fenvalerate (Yu and Nguyan, 1992). Chawla and Joia (1991) reported

development of resistance to fenvalerate and cypermethrin in the field populations of diamondback moth in Punjab. They reported that during a period of 5 years (1984-85 to 1988-89), there was gradual increase in LC_{50} value and this value increased by maximum of 22 times in fenvalerate for Jalandhar population and 10 times in cypermethrin for Ludhiana population. However, Joia and Udeaan (1998) reported very high levels of resistance varying from 1600 to 3200 and 1110 to 2830 to fenvalerate and cypermethrin, respectively in *P. xylostella* from different locations of Punjab. Raju and Singh (1995) reported 17.00 and 25.10 times resistance to fenvalerate in the field populations of *P. xylostella* collected from two locations of Varanasi district of Utter Pradesh but these populations showed only low levels of resistance to endosulfan (2.83 to 5.90 times).

Resistance to different insecticides reported from various parts of India and abroad might be due to their frequent and indiscriminate use by farmers leading to development of varying resistant strains.

5.2 Selection for resistance to malathion, endosulfan and fenvalerate in *P. xylostella*

Three lines namely, the malathion (MS), endosulfan (ES) and fenvalerate selected (FS) lines of *P. xylostella* were selected for resistance to malathion, endosulfan and fenvalerate, respectively. The toxicity data on the selection of these lines in comparison to the non-selected (NS) line have been presented in Tables 4.2.1 to 4.2.43 and summarized in Tables 5.2.1 to 5.2.4

Data (Table 5.2.1) showed that starting selection with 0.075 per cent malathion in the parental generation, a concentration of 1.15 per cent (15.33 times more than that of the initial concentration) was achieved in the 13th generation to cause a selection pressure of 60- 80 per cent kill of the 3rd instar larvae of *P. xylostella*. The LC_{50} value of malathion for the MS- lines

Table: 5.2.1 Information on the selection of malathion, – endosulfan – and fenvalerate – resistant strains of *P. xylostella*

Generation	No. of larvae treated	Selection with malathion		No. of larvae treated	Selection with éndosulfan		No. of larvae treated	Selectin with fenvalerate	
		Conc. applied (%)	Mortality (%)		Conc. applied (%)	Mortality (%)		Conc. applied (%)	Mortality (%)
Parental	200	0.075	66.00	300	0.05	65.00	200	0.015	61.00
G_1	200	0.10	62.50	300	0.075	71.33	200	0.020	65.00
G_2	200	0.15	70.00	300	0.10	66.00	200	0.020	60.00
G_3	150	0.20	72.00	300	0.15	64.00	200	0.025	67.00
G_4	150	0.20	65.33	300	0.20	65.33	200	0.050	75.00
G_5	150	0.30	63.33	300	0.25	72.00	200	0.050	65.00
G_6	200	0.35	65.50	200	0.30	61.00	200	0.075	63.00
G_7	200	0.40	71.00	200	0.40	60.00	200	0.10	72.00
G_8	200	0.60	64.00	200	0.50	65.00	200	0.10	68.00
G_9	250	0.65	60.80	200	0.60	61.50	150	0.15	64.00
G_{10}	250	0.80	68.00	200	0.75	68.00	150	0.15	61.33
G_{11}	250	1.00	63.20	200	0.80	70.00	150	0.20	69.33
G_{12}	250	1.00	67.20	200	0.80	65.50	150	0.20	64.66
G_{13}	250	1.15	74.80	200	0.90	71.00	150	0.25	70.00

Table: 5.2.2 Toxicity of malathion to the 3rd instar larvae of the non- selected (NS) and the malathion selected (MS) lines of *P. xylostella* in successive generations of selection

Generation	Line	Heterogeneity	Regression equation (y=)	Slope (b)	LC_{50}	Fiducial limits (%)	Resistance level
Parental		χ^2 (3) = 1.199	1.512x + 2.534	1.512x ± 0.223	0.043	0.033- 0.057	
G_1	NS	χ^2 (3) = 0.943	1.777x + 2.454	1.777x ± 0.237	0.041	0.032-0.052	
	MS	χ^2 (3) = 1.127	1.605x + 2.241	1.605x ± 0.282	0.052	0.038-0.072	1.27
G_2	NS	χ^2 (3) = 1.735	1.633x + 2.401	1.633x ± 0.217	0.039	0.032-0.053	
	MS	χ^2 (3) = 0.548	1.765x + 1.731	1.765x ± 0.289	0.071	0.053-0.096	1.82
G_3	NS	χ^2 (3) = 0.621	1.710x + 2.228	1.710x ± 0.226	0.042	0.033-0.053	
	MS	χ^2 (3) = 0.339	1.471x + 2.165	1.471x ± 0.267	0.087	0.060-0.118	2.07
G_4	NS	χ^2 (3) = 3.267	1.430x + 2.704	1.430x ± 0.220	0.040	0.031-0.055	
	MS	χ^2 (3) = 0.561	1.366x + 2.214	1.366x ± 0.270	0.109	0.076-0.157	2.73
G_5	NS	χ^2 (3) = 5.133	1.749x + 2.228	1.749x ± 0.239	0.038	0.030-0.049	
	MS	χ^2 (3) = 0.815	1.898x + 0.818	1.898x ± 0.313	0.159	0.121-0.210	4.18
G_6	NS	χ^2 (3) = 1.220	1.515x + 2.612	1.515x ± 0.223	0.037	0.039-0.054	
	MS	χ^2 (3) = 0.144	1.773x + 1.000	1.773x ± 0.299	0.179	0.136-0.239	4.84
G_7	NS	χ^2 (3) = 3.415	1.548x + 2.563	1.548x ± 0.224	0.038	0.029-0.049	
	MS	χ^2 (3) = 1.548	2.121x + 0.354	2.121x ± 0.354	0.238	0.184-0.306	6.26
G_8	NS	χ^2 (3) = 2.265	1.434x + 2.726	1.434x ± 0.223	0.039	0.029-0.051	
	MS	χ^2 (3) = 0.581	1.920x + 2.116	1.920x ± 0.353	0.318	0.245-0.411	8.15
G_9	NS	χ^2 (3) = 0.698	1.498x + 2.629	1.498x ± 0.228	0.038	0.029-0.051	
	MS	χ^2 (3) = 6.172	2.251x + 1.194	2.251x ± 0.447	0.491	0.395-0.608	12.92
G_{10}	NS	χ^2 (3) = 2.188	1.701x + 2.403	1.701x ± 0.237	0.034	0.026-0.044	
	MS	χ^2 (3) = 0.678	2.453x + 0.766	2.453x ± 0.481	0.532	0.435-0.650	15.65
G_{11}	NS	χ^2 (3) = 0.526	1.549x + 2.584	1.549x ± 0.234	0.036	0.028-0.048	
	MS	χ^2 (4) = 2.186	2.713x + 0.024	2.713x ± 0.402	0.685	0.574-0.819	19.03
G_{12}	NS	χ^2 (3) = 0.648	1.863x + 2.125	1.863x ± 0.237	0.035	0.028-0.049	
	MS	χ^2 (3) = 2.375	3.001x - 0.655	3.001x ± 0.449	0.776	0.667-0.880	22.17
G_{13}	NS	χ^2 (3) = 1.246	1.689x + 2.431	1.689x ± 0.245	0.033	0.026-0.043	
	MS	χ^2 (3) = 2.644	3.169x - 1.057	3.169x ± 0.445	0.814	0.714-0.928	24.67
G_{14}	NS	χ^2 (3) = 0.788	1.754x + 2.382	1.754x ± 0.235	0.031	0.024-0.040	
	MS	χ^2 (3) = 3.471	2.682x - 0.169	2.682x ± 0.398	0.847	0.724-0.990	27.32

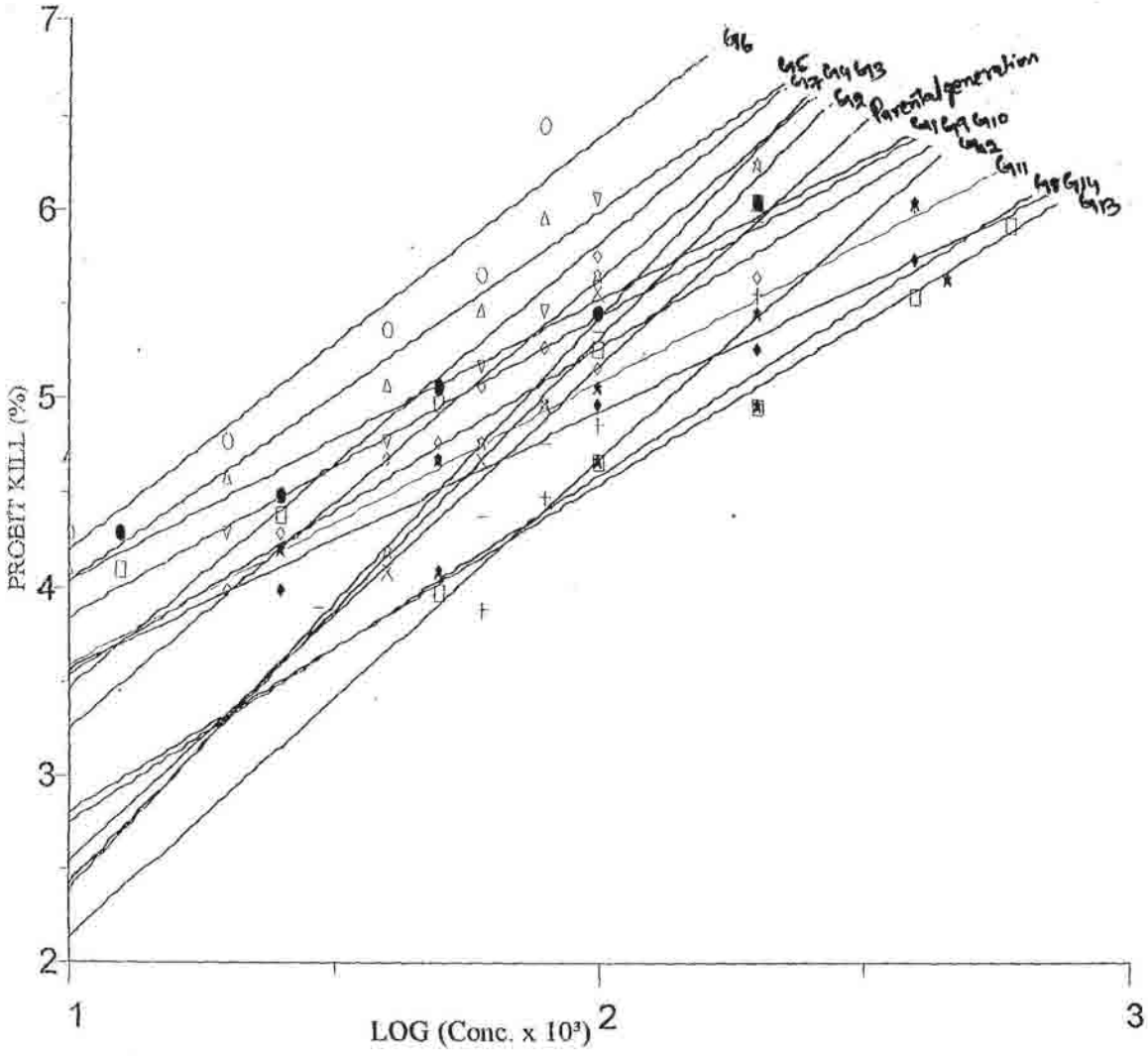


Fig. 5.2.1 Log (Conc).- Probit mortality regression lines for malathian to 3rd instar larve of parental and subsequent generation of the malathian - selected strain of *P. xylostella*.

Table: 5.2.3 Toxicity of endosulfan to the 3rd instar larvae of the non- selected (NS) and the endosulfan selected (ES) lines of *P. xylostella* in successive generations of selection

Generation	Line	Heterogeneity	Regression equation (y=)	Slope (b)	LC_{50}	Fiducial limits (%)	Resistance level
Parental		χ^2 (4)= 5.107	1.201x + 3.151	1.201 ± 0.169	0.035	0.026 - 0.047	
G_1	NS	χ^2 (3)=0.838	1.202x + 3.179	1.202 ± 0.227	0.033	0.024 - 0.045	
	ES	χ^2 (4)=0.179	1.321x + 2.904	1.321 ± 0.170	0.039	0.029 - 0.051	1.18
G_2	NS	χ^2 (4)=0.642	1.301x + 3.065	1.301 ± 0.170	0.031	0.023 - 0.041	
	ES	χ^2 (4)=1.033	1.821x + 1.679	1.821 ± 0.197	0.068	0.054 - 0.083	2.19
G_3	NS	χ^2 (3)=0.066	1.202x + 3.197	1.202 ± 0.214	0.032	0.022 - 0.043	
	ES	χ^2 (3)=2.400	1.729x + 1.739	1.729 ± 0.237	0.077	0.059 - 0.099	2.41
G_4	NS	χ^2 (4)=1.802	1.278x + 3.109	1.278 ± 0.169	0.030	0.023 - 0.041	
	ES	χ^2 (3)=1.302	1.696x + 1.654	1.696 ± 0.230	0.094	0.073 - 0.119	3.13
G_5	NS	χ^2 (4)=0.654	1.234x + 3.225	1.234 ± 0.169	0.027	0.021 - 0.039	
	ES	χ^2 (3)=0.034	1.889x + 0.991	1.889 ± 0.241	0.132	0.106 - 0.166	4.89
G_6	NS	χ^2 (4)=1.171	1.371x + 2.995	1.371 ± 0.169	0.029	0.022 - 0.038	
	ES	χ^2 (3)=0.316	2.109x + 0.233	2.109 ± 0.268	0.182	0.148 - 0.225	6.28
G_7	NS	χ^2 (3)=2.359	1.318x + 3.048	1.318 ± 0.221	0.030	0.022 - 0.041	
	ES	χ^2 (3)=1.575	1.739x + 0.859	1.739 ± 0.249	0.240	0.188 - 0.305	8.00
G_8	NS	χ^2 (3)=1.627	1.365x + 3.008	1.365 ± 0.232	0.029	0.021 - 0.039	
	ES	χ^2 (3)=4.027	2.147x + 1.849	2.147 ± 0.291	0.293	0.241 - 0.356	10.10
G_9	NS	χ^2 (4)=1.101	1.148x + 3.340	1.148 ± 0.167	0.028	0.013 - 0.031	
	ES	χ^2 (3)=1.708	2.111x + 1.596	2.111 ± 0.296	0.409	0.337 - 0.497	14.61
G_{10}	NS	χ^2 (3)=0.555	1.238x + 3.251	1.238 ± 0.223	0.026	0.018 - 0.038	
	ES	χ^2 (3)=3.803	3.228x - 0.562	3.228 ± 0.131	0.528	0.465 - 0.600	20.31
G_{11}	NS	χ^2 (3)=1.541	1.393x + 2.951	1.393 ± 0.234	0.029	0.022 - 0.039	
	ES	χ^2 (3)=2.058	3.609x - 1.382	3.609 ± 0.472	0.586	0.521 - 0.659	20.21
G_{12}	NS	χ^2 (3)=1.319	1.429x + 3.004	1.429 ± 0.224	0.025	0.019 - 0.033	
	ES	χ^2 (3)=2.510	3.537x - 1.373	3.537 ± 0.477	0.634	0.559 - 0.719	25.36
G_{13}	NS	χ^2 (4)=1.372	1.179x + 3.383	1.179 ± 0.176	0.024	0.016 - 0.028	
	ES	χ^2 (3)=3.145	3.261x - 0.938	3.261 ± 0.476	0.662	0.588 - 0.765	27.58
G_{14}	NS	χ^2 (3)=1.220	1.371x + 3.123	1.371 ± 0.229	0.023	0.017 - 0.032	
	ES	χ^2 (3)=3.763	2.908x - 0.347	2.908 ± 0.455	0.689	0.596 - 0.799	29.96

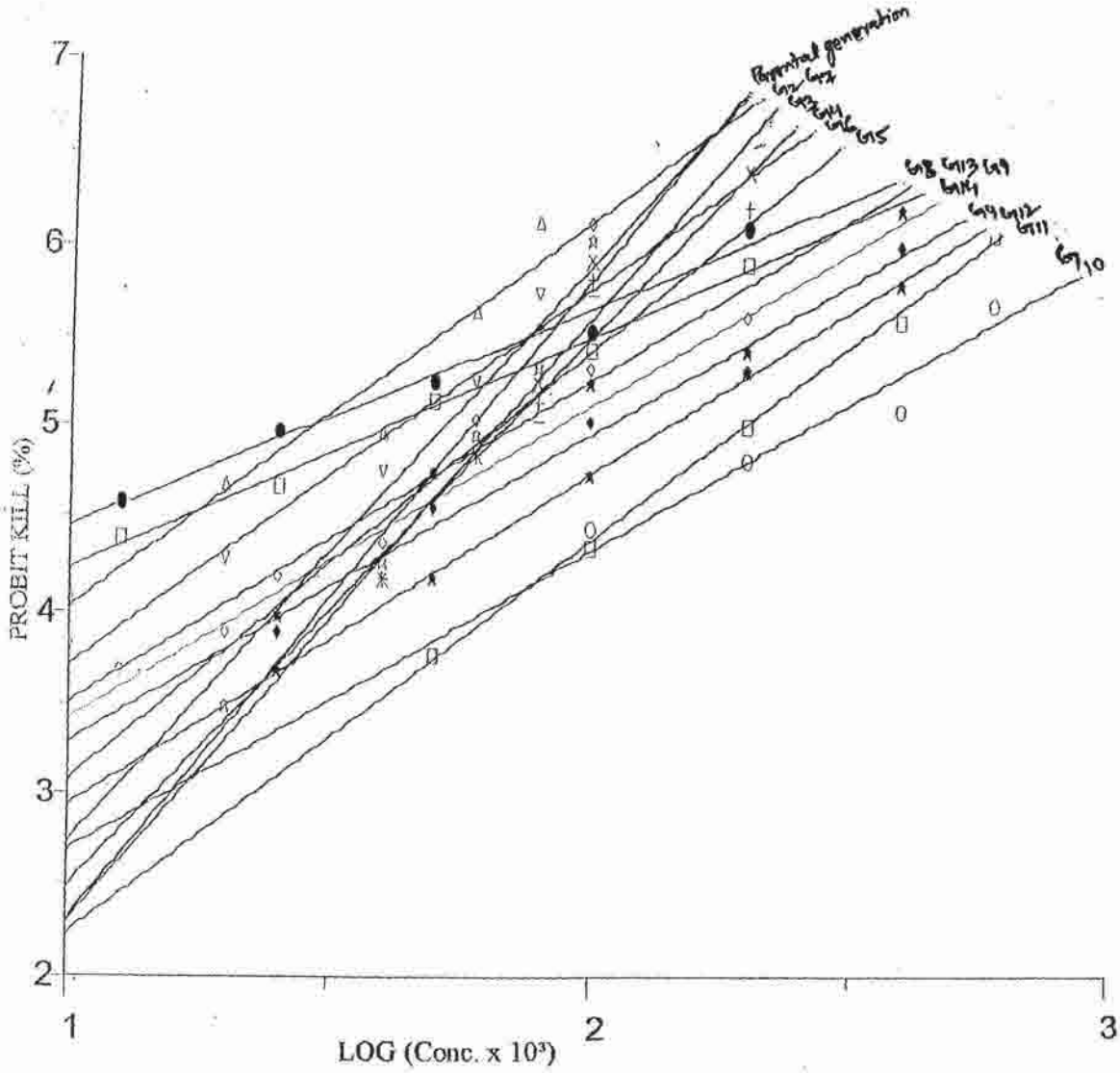


Fig. 5.2.2 Log (Conc).- Probit mortality regression lines for endosulfan to 3rd instar larve of parental and subsequent generation of the endosulfan - selected strain of *P. xylostella*.

Table: 5.2.4 Toxicity of fenvalerate to the 3rd instar larvae of the non- selected (NS) and the fenvalerate selected (ES) lines of *P. xylostella* in successive generations of selection

Generation	Line	Heterogeneity	Regression equation (y=)	Slope (b)	LC_{50}	Fiducial limits (%)	Resistance level
Parental		χ^2 (3)= 1.288	1.589x + 3.434	1.589± 0.226	0.00961	0.00731 - 0.01239	
G_1	NS	χ^2 (3)=0.489	1.486x + 3.545	1.486 ± 0.221	0.00953	0.00726 - 0.01250	
	FS	χ^2 (3)=0.229	1.585x + 3.426	1.585 ± 0.234	0.00979	0.00753 - 0.01274	1.03
G_2	NS	χ^2 (3)=0.262	1.312x + 3.719	1.312 ± 0.217	0.00947	0.00698 - 0.01283	
	FS	χ^2 (3)=0.699	1.504x + 3.385	1.504 ± 0.227	0.01185	0.00902 - 0.01558	1.25
G_3	NS	χ^2 (3)=0.445	1.484x + 3.573	1.484 ± 0.222	0.00916	0.00697 - 0.01203	
	FS	χ^2 (3)=0.628	1.808x + 2.936	1.808 ± 0.235	0.01384	0.01098- 0.01743	1.51
G_4	NS	χ^2 (3)=0.218	1.469x + 3.669	1.469 ± 0.224	0.00804	0.00607 - 0.01065	
	FS	χ^2 (3)=1.758	1.679x + 2.829	1.679 ± 0.230	0.01965	0.01528 - 0.02525	2.44
G_5	NS	χ^2 (3)=0.145	1.571x + 3.578	1.571 ± 0.226	0.00844	0.00564 - 0.01146	
	FS	χ^2 (3)=1.187	1.537x + 2.895	1.537 ± 0.221	0.02343	0.01800 - 0.03049	2.78
G_6	NS	χ^2 (3)=0.092	1.633x + 3.557	1.633 ± 0.230	0.00765	0.00543 - 0.00963	
	FS	χ^2 (3)=1.258	1.385x + 2.939	1.385 ± 0.219	0.03074	0.02294 - 0.04118	4.02
G_7	NS	χ^2 (3)=0.963	1.272x + 3.877	1.272 ± 0.218	0.00763	0.00491 - 0.01186	
	FS	χ^2 (3)=4.878	1.751x + 2.174	1.751 ± 0.246	0.04109	0.03217 - 0.05246	5.39
G_8	NS	χ^2 (3)=0.219	1.486x + 3.723	1.486 ± 0.228	0.00723	0.00590 - 0.00992	
	FS	χ^2 (3)=2.307	1.579x + 2.336	1.579 ± 0.223	0.04862	0.03761 - 0.06284	6.73
G_9	NS	χ^2 (3)=0.798	1.475x + 3.747	1.475 ± 0.230	0.00707	0.00527 - 0.00948	
	FS	χ^2 (3)=1.815	1.695x + 1.905	1.695 ± 0.232	0.06689	0.05223 - 0.08566	9.47
G_{10}	NS	χ^2 (3)=0.469	1.549x + 3.691	1.549 ± 0.235	0.00700	0.00528 - 0.00928	
	FS	χ^2 (3)=8.306	1.727x + 1.621	1.727 ± 0.201	0.09055	0.07143 - 0.11470	12.94
G_{11}	NS	χ^2 (3)=0.372	1.186x + 4.017	1.186 ± 0.216	0.00674	0.00475 - 0.00956	
	FS	χ^2 (3)=0.692	1.913x + 1.228	1.913 ± 0.241	0.09366	0.07506 - 0.11684	13.89
G_{12}	NS	χ^2 (3)=1.090	1.184x + 3.999	1.184 ± 0.216	0.00700	0.00402 - 0.00997	
	FS	χ^2 (3)=0.249	1.871x + 1.230	1.871 ± 0.242	0.10355	0.08256 - 0.12985	14.79
G_{13}	NS	χ^2 (3)=1.022	1.505x + 3.897	1.505 ± 0.232	0.00541	0.00397 - 0.00736	
	FS	χ^2 (3)=0.955	2.023x + 2.908	2.023± 0.268	0.10806	0.08662 - 0.13507	19.24
G_{14}	NS	χ^2 (4)=0.654	1.234x + 4.069	1.234 ± 0.169	0.00567	0.00418 - 0.00769	
	FS	χ^2 (3)=0.443	2.002x + 2.964	2.002 ± 0.251	0.10409	0.08382 - 0.12925	19.06

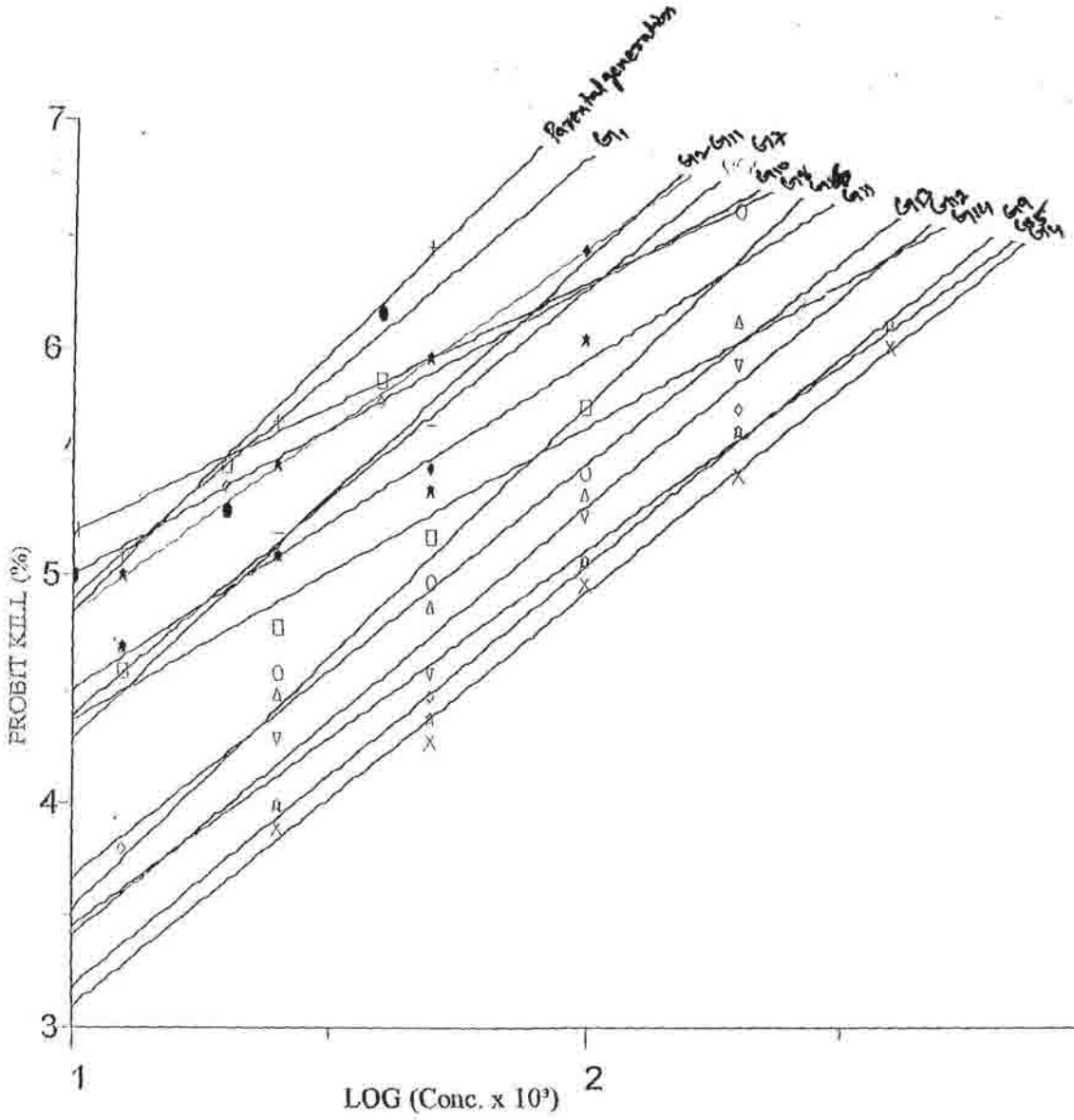


Fig. 5.2.3 Log (Conc).- Probit mortality regression lines for fenvalerate to 3rd instar larve of parental and subsequent generation of the fenvalerate - selected strain of *P. xylostella*.

increased from 0.043 per cent in the parental generation to 0.847 per cent in the 14th generation (Table 5.2.2). In comparison to NS- line, the resistance level of the MS- line increased to 27.32- fold in 14th generation of continuous selection with malathion.

Results showed that in the initial generations, rate of development of resistance to malathion has been found to be slow particularly up to G_2 which is evident from the overlapping fiducial limits of LC_{50} values of the MS and NS-lines (Table 5.2.2). Difference started appearing after 3rd generation of selection when resistance level increased to 2.07 – fold. Similar trend was found in selection of a strain resistant to endosulfan (Table 5.2.3). Difference between the two lines viz., ES- and NS- lines started appearing in G_2 when resistance level increased to 2.19- fold. Selection with a concentration of 0.05 per cent endosulfan in the parental generation, a concentration of 0.90% (18 times more than the initial concentration) was achieved in the G_{13} to cause a selection pressure of 60-80% kill of the third instar larvae (Table 5.2.1). With continuous selection, LC_{50} value of endosulfan for the ES-line increased from 0.035 per cent in the parental generation to 0.689 per cent in the 14th generation and level of resistance to 29.96- fold.

The toxicity data on the selection of a strain resistant to fenvalerate (Table 5.2.1 and 5.2.4) showed that beginning with a concentration of 0.015 per cent of fenvalerate in parental generation, a concentration of 0.25 per cent (16.67 times more) than that of the initial concentration was achieved in the thirteenth generation to cause a selection pressure of 60-80 per cent kill of the 3rd instar larvae. The LC_{50} values of fenvalerate for the FS- line varied from 0.00961 per cent in the parental generation to 0.10409 per cent in the 14th generation (Table 5.2.4). In comparison to NS- line, resistance level of the FS- line increased to 19.06 fold after 14th generation (parental generation and G_1 to G_{13}) of continuous selection with fenvalerate.

The rate of development of resistance had also been slow in the initial generations of selection. This is evident from the overlapping fiducial limits of the LC_{50} values of the FS- and NS- lines up to G_3 generation (Table 5.2.4). Difference between the two lines for their susceptibility to fenvalerate started appearing after G_4 generation of selection when resistance level increased to 2.44-fold. From the results it can be inferred that *P. xylostella* has the potential to develop resistance to malathion, endosulfan and fenvalerate when subjected to selection pressure of these insecticides. In general, the rate of development of resistance to all the insecticides had been slow in the initial generations of selection. These findings are consistent with the studies conducted by Liu *et al.* (1995) on the selection of a strain of *P. xylostella* resistant to deltamethrin which showed that the development of resistance in this insect was slow in earlier stages, faster in the middle and rapid in the later stage. Senapati and Satpathy (1980, 1982) have also observed slow rate of development of resistance in *Epilachna sparsa* to malathion and carbaryl up to nine generations of selection. Similarly, Kumar and Kumar (1997, 1998) found slow rate of development of resistance in hadda beetle (*Epilachna vigintioctopunctata*) up to G_4 to malathion and G_3 to endosulfan.

Contrary to the present findings on the slow rate of development of resistance in the initial generations of selection, Noppun *et al.* (1987) found that after 8-9 generations of continuous selection pressure in *P. xylostella,* there is a rapid development of resistance to fenvalerate with in a short period of time. Wu and Gu (1986) found that in green house trials multiple applications of fenvalerate to control *P. xylostella,* resulted in a quick establishment of resistance in Shanghai, China. Similarly, Cheng and Sun (1986) showed that selection with fenvalerate, and mixture of fenvalerate and piperonyl butoxide resulted in the development of high levels of resistance to selection agents with in a few generations. Noppun *et al.*(1986),

however, contended that selection for resistance to fenvalerate in the field collected strains was limited, only slight resistance could be obtained after six selection treatments for 23 generations. Development of resistance depends upon the complex interactions of many factors and the speed at which this occurs is unpredictable (Georghiou and Taylor, 1977). Slow rate of development of resistance to malathion, endosulfan and fenvalerate in earlier generations as found in the present study might be due to lower proportion of the insects having the resistant factors in the beginning.

Results also show that selection with malathion, endosulfan and fenvalerate for 13 generations resulted into strains which were 27.32-, 29.96- and 19.06- fold resistant to respective insecticides in comparison to non-selection line. These findings have close conformity with Kim *et al.* (1990) who reported that *P. xylostella* developed 66.2- fold resistance as compared to parent strain after 24 generations of selection pressure of fenvalerate. Doichuanngam and Thornhill (1989) also reported that selection of the susceptible strain with malathion over 8 generations gave rise to an increased resistance to malathion. Development of malathion resistance (7.2- fold) within eight generations of selection with malathion in the laboratory has also been reported in *Nilaparvata lugens* (Wang *et al.,* 1988). Kumar and Kumar (1997, 1998) also reported that up to 9th generation of selection pressure, *Epilachna vigintioctopunctata* (Fab.) developed 7.79 and 6.59 times resistance to malathion and endosulfan, respectively. On the basis of explanation given by Hoskins and Gordon (1956), a long initial period is to be expected if the resistance factors are very rare in the population and rapid increase in resistance is possible only after they spread through considerable fraction of the population. Milani (1960), however, considered the first few generations to constitute a period during which the gene alleles are accumulated, incompatible

ones are eliminated and genotype as a while is re- modeled to receive the new gene alleles. Brown and Pal (1971) stated that at the beginning of a selection process, slight increase in LD_{50}'s may be independent of specific genes for resistance. The term "vigour tolerance" was applied to this phenomenon by Hoskins and Gordon (1956). The expression implies that weaker individuals showing more vigour, survive. This effect might have been exhibited in the early generations of selection with malathion, endosulfan and fenvalerate in the present study. Georghiou and Taylor (1976) stated that in most cases of laboratory selection, resistance develops gradually at first, subsequently at a faster rate and is dependent upon the phenotypic expression of R- gene (S) in the resistant homozygotes. Slow rate of development of resistance to malathion, endosulfan and fenvalerate in the initial generations of selection is also exhibited by the trend of the log (concentration) – probit mortality regression (Lc-p) lines drawn for parental and different generations of the MS-, ES- and FS- lines. Implications of the changes in Lc-p lines were clarified by Brown (1959) who stated that " the development of true resistance was characterized by the regression lines becoming shallower as these moved to the right, finally to become steeper again as the resistance come to characterize the population." In the present finding also, Lc- p lines were observed to move gradually to right during the process of selection with, malathion, endosulfan and fenvalerate.

It could, therefore, be concluded that *P. xylostella* has the potential to develop resistance to malathion, endosulfan and fenvalerate when subjected to selection pressure of these insecticides.

5.3 Cross- resistance spectrum of the malathion-, endosulfan- and fenvalerate-resistant strains of *P. xylostella* :

The toxicity of various insecticides was tested against malathion- resistant (MR) -, endosulfan- resistant (ER)-, and fenvalerate resistant (FR)– strains, obtained after thirteen generations of selection with the respective insecticides. The strains were 27.32-, 29.96- and 19.06- times resistant to malathion, endosulfan and fenvalerate, respectively, as compared to the susceptible strains. The toxicity data of different insecticides, their comparative LC_{50} values for the resistant and susceptible strains and the ratio of LC_{50} for the resistant strain vis-à-vis susceptible strain (Tables 4.3.1 to 4.3.6 and Table 4.3.7) show an increase in the LC_{50} value for the resistant strains, the order of increase for malathion resistant strain being: cypermethrin 1.37x, lambda- cyhalothrin 1.43x, fenvalerate 2.15x, monocrorophos 2.30x and endosulfan 3.61x. Thus malathion resistant strain showed cross-resistance ranging from 1.37 to 3.61 to these insecticides.

The order of increase in LC_{50} value for endosulfan resistant strain was: cypermethrin 1.07x, lambda-cyhalothrin 1.15x, monocrotophos 1.38x, fenvalerate 1.71x and malathion 2.26x. Thus endosufan resistant strain showed cross-resistance ranging from 1.07 to 2.26 to these insecticides. In case of fenvalerate- resistant strain, the order of increase was: monocrotophos 1.15x, lambda-cyhalothrin 1.29x, malathion 1.68x, endosulfan 2.91x and cypermethrin 2.28x. Thus cross-resistance ranged from 1.15 to 2.28 to these insecticides.

Data presented in Tables 4.3.1 to 4.3.6 and summerised in Table 4.3.7 show that the selection for resistance to malathion, endosulfan and fenvalerate has resulted in cross-

resistance to the insecticides belonging to different groups, although the degree of cross-resistance shown is of relatively very low order. The results are not unexpected as selection with one insecticide often results in some degree of resistance to other insecticides belonging to different groups. Such small changes or non- specific increase or decrease in susceptibility of resistant strains are likely to occur as a consequence of selection with a particular insecticide and are not considered as definite cases of cross- resistance. Such non-specific type of resistance should be called "Vigour tolerance" (Hoskins and Gardon, 1956). However, a low-level of cross-resistance (vigour tolerance) to other insecticides belonging to different groups may predispose them to the rapid development of resistance on their introduction for control (Anonymous, 1970). There is no literature on the cross-resistance spectrum of strain (s) of *P. xylostella* resistant to malathion. However, work has been done on the related insecticides. Liu *et al.* (1981) reported that diazinon-resistant strain (15.1x) of this insect showed cross-resistance to permethrin (47.6x), cypermethrin (21.2x), decamethrin (25.7x) and fenvalerate (20.8x). It was further reported that methomyl-resistant strain (2.8x) had slight yet consistent negative cross- resistance to permethrin (0.5x), cypermethrin (0.3x) and decamethrin (0.2x) except fenvalerate (3.8x). Cheng *et al.* (1985) also found that resistance to some organophosphate compounds could result in the cross- resistance to synthetic pyrethroids. However, Wang and Feng (1986) reported that populations selected for resistance to mevinphos showed decreased cross-resistance to fenvalerate. Population found highly resistant to organophosphates were also highly susceptible to cartap and a mixture of fenvalerate and di methoate (Kimura, 1989). Joia *et al.* (1996) also reported that quinalphos resistance (70 times) in *P. xylostella* did not extend to cartap hydrochloride. There is no literature on the cross-resistance spectrum of strain (s) of *P. xylostella* resistant to endosulfan.

Present finding reveal that fenvalerate resistant strain of *P. xylostella* does not show any significant cross-resistance to cypermethrin and lambda-cyhalothrin belonging to same group of synthetic pyrethroids which are α- cyno-3-phenoxy benzyl esters. The susceptibility of fenvalerate resistant strain to both these insecticides could be due to structural differences (difference in the groups attached to the basic structure leading to toxicity of insecticides). On the contrary, Liu *et al.* (1995) reported that deltamethrin resistant (1163-fold) strain of this insect had positive cross-resistance to cypermethrin. Present finding also reveals that fenvalerate resistant strain does not show any cross-resistance to insecticides belonging to other groups i.e. organophosphates and cyclodiene. Similar findings were reported by Cheng and Sun (1986). *Liu et al.* (1995) also reported that deltamethrin resistant (1163-fold) strain showed little cross- resistance to DDVP and methomyl. Similarly, strains of *P. xylostella* resistant to fenvalerate (2700 times) and cypermethrin (2800 times) did not show any cross-resistance to cartap hydrochloride (Joia *et al.*, 1996)

Lower level of cross-resistance to different groups of insecticides have earlier been reported in the case of strains of *Tribolium castaneum* (Herbst.) resistant to p,p'-DDT (Bhatia and Pradhan, 1970), Lindane (Kumar and Bhatia, 1981) and malathion (Shukla *et al.,* 1989). Low levels of cross-resistance to lindane (1.22x) and carbaryl (1.19x) in a malathion resistant strain (23.32x) and to fenitrothion (1.27x), malathion (0.78x) and lindane (2.28x) in carbaryl resistant strain (8.20x) of *Epilachana sparsa* (Herbst.) were also reported by Senapati and Satpathy (1981a, 1982). Brun *et al.* (1994) reported that endosulfan selected strain of *Hypothenemus hampei* (Ferrari) (2600-fold) showed low level of cross- resistance to malathion (1.4x), chlorpyriphos (0.9x), fenitrothion (1.3x) and carbaryl (2.5x). Kumar and Kumar (1998) reported that malathion resistant strain (7.79x) of *Epilachna vigintioctopunctata*

(Fab.) showed little cross-resistance to cypermethrin (1.20x), fenvalerate (1.20x), monocrotophos (1.90x), carbaryl (1.30x) and endosulfan (2.24x). It was further reported that endosulfan resistant strain of this insect also showed little cross-resistance to cypermethrin (1.10x), fenvalerate (1.07x), monocrotophos (1.20x), malathion (2.60x) and carbaryl (1.17x).

5.4 Comparative biological characteristics of the resistant and susceptible strains of *P. xylostella*

Studies on the biological characteristics of malathion-resistant (MR), endosulfan-resistant (ER) and fenvalerate-resistant (FR) strains as compared to the susceptible strains (S) were carried out to find out if resistance to malathion, endosulfan and fenvalerate involves any change in the biological characteristics. After 14th generation of selection pressure, the MR, ER and FR- strains were found 27.32-, 29.96- and 19.06- times resistant to malathion, endosulfan and fenvalerate, respectively.

The incubation period of the resistant strains of *P. xylostella* has been observed to vary from 2 to 6 days and for susceptible strain from 2 to 4 days (Table 4.4.1). Average incubation period was significantly longer for the resistant strains than the susceptible strains (2.79 days). The average incubation period of strains resistant to malathion, endosulfan and fenvalerate was 3.54, 3.29 and 3.83 days, respectively. Among the resistant strains, fenvalerate-resistant strain had significantly longer incubation period than endosulfan- resistant strain but it did not different significantly from malathion-resistant strain. The per cent survival of eggs of the three resistant strains was significantly at par with the susceptible strain.

Total larval period of the susceptible strain varied from 5 to 10 days with an average of 8.19 days. In resistant strains, it varied from 5 to 10 days with an average of 6.74, 7.27 and 6.53 days in MR, ER and FR strains, respectively. The average larval period of S-strain was

significantly longer than the three resistant strains. The per cent survival of larvae of the resistant strains (malathion-resistant, endosulfan-resistant and fenvalerate-resistant) was non-significant and at par with the susceptible strain.

Pupal duration was significantly longer in susceptible strain (4.52 days) as compared to malathion- resistant (3.94 days), endosulfan-resistant (3.84 days) and fenvalerate-resistant (3.58 days) strains. Three resistant strains did not differ significantly with one another in respect of duration of pupal stage. There was no significant difference among the susceptible and resistant – strains for per cent survival of pupae.

Total developmental period of the three resistant strains viz., malathion- resistant (14.25 days), endosulfan- resistant (14.48 days) and fenvalerate- resistant (13.74 days) was significantly shorter than the susceptible strain (15.76 days). The total developmental period of resistant strains was shorter than the susceptible strain mainly due to short duration of larval and pupal periods.

The pre-oviposition period of three resistant strains varied from 2 to 5 and for susceptible strain from 1 to 5 days. All the four strains were statistically at par for pre-oviposition period.

Data presented in the Table 4.4.2 showed that the average oviposition period for MR, ER, FR and S- strains was 6.2, 6.5, 5.9 and 6.6 days, respectively and were statistically non-significant with one another. The number of eggs laid per female in case of MR, ER, FR and S – strains was 198.40, 202.30, 211.00 and 194.10, respectively and the four strains did not differ significantly with one another for fecundity.

Results on the biology of susceptible and resistant strains show that the resistant strains have shorter developmental period. The fecundity of the resistant strains is not impaired and

there was no adverse affect on the survival of eggs, larvae and pupae. Thus after selection with malathion, endosulfan and fenvalerate, the insect has become biologically superior.

Result on the biological characteristics of the resistant strains in comparison to susceptible strain showed that resistant strains have shorter developmental period, but no adverse affect on the fecundity, and survival of eggs, larvae and pupae. It is thus concluded that the resistant strains of *P. xylostella* had become biologically superior to the susceptible strain by having significantly faster development. Selection for resistance to insecticides had often resulted into changes in the biological characteristics of the resistant strains (Bielarski *et al.*, 1957; Bhatia and Pradhan, 1968, 1971; Verma and Ram, 1973; Saxena and Bhatia, 1980; Bansode and Bhatia, 1981; Senapati and Satpathy, 1981; Kumar and Bhatia, 1983; Campanhola *et al*,1991; O' Brien and Graves 1992; Yamada *et al.*, 1993 and Kumar and Kumar, 1997). In some cases development of resistance to insecticides has been associated with the detrimental affect on the biology whereas in others, the differences between susceptible and resistant strains are either small or the resistant strains seem to have an advantage.

Present finding receives support from Yamada *et al.* (1993) who found that after 14 and 15 generations of with and without selection with chlorfluazuron resulted into strains of *P. xylostella* which had reacquired high level of resistance to chlorfluazuron and had a higher intrinsic rate of natural increase, shorter generation times and higher reproductive rate than non – selected strains. Verma and Ram (1973) also reported that malathion- resistant strain of *T. castaneum* had shorter oviposition and larval period and greater fecundity. No difference in the incubation period, hatching ratio, duration of pupal stage, rate of successful pupation and adult emergence. Similar findings were also reported by Kumar and Bhatia (1983) that the

resistant strain reared with or without insecticidal pressure had 3-4 days shorter developmental duration than the susceptible one. The fecundity of the resistant strains was not impaired. After prolonged exposure to lindane, the insect had become biologically superior by having significantly faster development.

Contrary to the present finding, Saito *et al.* (1992) reported that the biology of strains of *P. xylostella* susceptible and resistant to synthetic pyrethroids was found to be similar, having short life-cycle, high fecundity, short larval and adult periods. A decrease in biological potential has been reported by Thomas and Brazzel (1961) with endrin in *Anthonomus grandis* (Boh.), Lloyd and Parkin (1963) with pyrethrins, Upitis *et al.* (1973) with methyl bromide in *Sitophilus granarius*(L.); Bansode (1974) with malathion, Tewari and Pandey (1977) with p, p'-DDT and malathion in *Sitophilus oryzae* (L.); Bhatia and Pradhan (1968) with p,p'-DDT, Winks (1971, 1973) with phosphine in *Tribolium castaneum* (Herbst); Senapati and Satpathy (1981) with malathion and carbaryl in *Epilachana sparsa* (Fab.), Campanhola *et al.*(1991) with pyrethroids in *Heliothis virescens* (Hubner); Kumar and Kumar (1997) with malathion and endosulfan in *Epilachna vigintioctopunctata* (Fab.)

The present findings thus reveal that if selection with malathion, endosulfan and fenvalerate over a prolonged period takes place in the field population of *P. xylostella*, the population of the resistant strains is likely to be increased with greater speed. Consequently, resistant strains will become abundant in nature. These findings offer a possible explanation for the predomination of resistant insects after the introduction of insecticides. The development of resistance to malathion, endosulfan and fenvalerate in the field populations of insects can create a serious problem.

SUMMARY

SUMMARY

The investigation entitled "Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)" was carried out in the Department of Entomology, CSK HPKV, Palampur from March, 2000 to July, 2001 and in the Entomology laboratory, CSK HPKV, Hill Agricultural Research and Extension Centre, Bajaura from August, 2001 to August, 2002. Larvae and pupae of diamondback moth, *P. xylostella* collected from thirteen vegetable growing localities viz, Kalheli, Garasa, Hurla, Chailchock, Balh, Rampur, Santogarh, Nadaun, Jamanabad, Samloti, Theog, Matyana and Sandhu of Himachal Pradesh and reared in the laboratory for one generation, were tested for their susceptibility to malathion, endosulfan and fenvalerate in the third larval instar by using direct spray method of bioassay.

The LC_{50} values of malathion, endosulfan and fenvalerate varied from 0.0231 to 0.0491, 0.0252 to 0.0386 and 0.00708 to 0.01070 per cent, respectively. LC_{50} values of these insecticides for different populations of *P. xylostella*, however, did not differ significantly showing thereby that different populations collected from different vegetable growing areas of Himachal Pradesh were statistically at par with one another for their susceptibility to these insecticides. On the basis of relative toxicity calculated by dividing the LC_{50} value of a particular insecticide to different populations with the LC_{50} value for the most susceptible population, malathion was found to be comparatively more toxic to the population collected

from Samloti area. It was relatively less toxic (1.165 to 2.126 times) to populations collected from other areas of the state. Resistance ratios calculated by dividing LC_{99} value of a particular insecticide for a population with the field recommended dose of that insecticide showed that populations from Rampur, Sandhu, Theog, Matyana, Balh, Chailchock, Hurla and Kalheli were comparatively more tolerant to malathion (19.36 to 29.72 fold resistance ratios). For endosulfan, Nadaun population was the most susceptible. In comparison to the toxicity of endosulfan to Nadaun population, endosulfan was 1.008 to 1.532 times less toxic to populations from other areas. Based on LC_{99} values population from Nadaun area was the least resistant (7.76- fold resistance ratio) to endosulfan while population from Matyana area was the most resistant (21.08- fold RR). Resistance ratio of endosulfan for populations from other areas varied from 08.45 to 19.54. For fenvalerate, populations from Kalheli, Hurla, Chailchock, Balh, Santogarh, Jamanabad, Theog, Matyana and Sandhu were comparatively more resistant (20.20 to 31.00- fold resistance ratios). Average resistance ratios (average of 13 populations) of malathion, endosulfan and fenvalerate for 3rd instar larvae was worked out to be 19.89, 15.07 and 26.44, respectively.

Selection of 3rd instar larvae of *P. xylostella* for resistance to malathion, endosulfan and fenvalerate by applying a selection pressure of 60-80 per cent kill in every generation, resulted into 27.32, 29.96 and 19.06 times resistance to respective insecticides after fourteen generations (parental and G_1 to G_{13}) of selection in comparison to the non-selected strain. The rate of development of resistance to all the three test insecticides was found to be little slower in the initial generations of selection.

The cross- resistance pattern of the strains of *P. xylostella* resistant to malathion (27.32-fold), endosulfan (29.96-fold) and fenvalerate (19.06- fold) was studied by comparing

the LC_{50} values of various insecticides for the resistant and susceptible strains. The malathion-resistant strain showed cross-resistance ratios of 2.15-, 3.61-, 2.30-, 1.37- and 1.43- fold to fenvalerate, endosulfan, monocrotophos, cypermethrin and lambda-cyhalothrin, respectively. The endosulfan-resistant strain showed cross-resistance ratios of 2.26-, 1.07-, 1.71-, 1.38- and 1.15- times to malathion, cypermethrin, fenvalerate, monocrotophos and lambda-cyhalothrin, respectively. Cross-resistance ratios shown by fenvalerate-resistant strain to malathion, cypermethrin monocrotophos, endosulfan and lambda-cyhalothrin were 1.68-, 2.28-, 1.15-, 2.91-, and 1.29- times, respectively.

Studies on the biological characteristics of malathion-, endosulfan- and fenvalerate-resistant strains and the susceptible strain were carried on the cabbage leaves at 28 ± 1^0C and 70 ± 5 per cent relative humidity. The average incubation period of the malathion- resistant (3.54 days), endosulfan-resistant (3.29 days) and fenvalerate-resistant (3.83 days) strains was significantly longer than the susceptible strain (2.79 days). Average egg survival of MR, ER, FR and S strains was 92.00, 88.00, 88.00 and 93.20 per cent, respectively. But there were no significant differences among these strains for egg survival. Average larval period of susceptible strain was significantly longer (8.19 days) than the malathion-resistant (6.74 days), endosulfan-resistant (7.27 days) and fenvalerate-resistant (6.53 days) strains.

All these strains were found to be statistically similar for larval survival. The pupal period of malathion-, endosulfan-, fenvalerate-resistant strains and the susceptible strain was 3.94, 3.84, 3.58 and 4.52 days, respectively and there were non-significant differences among the strains for pupal duration. The percent survival of the pupae of different strains was found to be non-significant.

The total developmental period of the susceptible strain (15.76 days) was significantly longer than malathion-resistant (14.25 days), endosulfan-resistant (14.48 days) and fenvalerate-resistant (13.74 days) strains. The pre-oviposition period of the susceptible, malathion-resistant, endosulfan-resistant and fenvalerate-resistant strains was 2.5, 2.9, 2.8 and 3.3 days, respectively. The duration of oviposition period of the respective strains was 6.6, 6.2, 6.5 and 5.9 days. Four strains were found to be statistically at par with one another for the duration of pre-oviposition and oviposition periods. Fecundity of susceptible strain, malathion-resistant, endosulfan-resistant and fenvalerate-resistant strains was 194.10, 198.40, 202.30 and 211.00 eggs per female, respectively and there were no significant differences among these strains for fecundity. Thus, resistant strains had become biologically superior by having shorter developmental period, with no adverse affect on fecundity and survival of eggs, larvae and pupae.

It can be concluded from the present investigations:

- On the basis of LC_{50} values, populations of *P. xylostella* collected from different vegetable growing areas of Himachal Pradesh are found similar in their susceptibility to malathion, endosulfan and fenvalerate.
- The LC_{50} of malathion, endosulfan and fenvalerate obtained from the present study can be used as base line data for further comparisons to monitor any change in susceptibility of *P. xylostella* to these insecticides in Himachal Pradesh.
- Based on the resistance ratios, *P. xylostella* has developed moderate level of resistance to malathion, endosulfan, and fenvalerate in the state. In comparison to malathion and endosulfan, resistance to fenvalerate was comparatively higher.

Therefore, there is a need to revise recommendations and alternate use of insecticides belonging to different groups.

- In laboratory, studies confirmed that *P. xylostella* has the potential to develop resistance to malathion, endosulfan and fenvalerate when field collected populations of this insect are subjected to selection pressure of these insecticides for a prolonged duration.
- Malathion-, endosulfan- and fenvalerate- resistant strains showed low levels of cross-resistance to cypermethrin, monocrotophos and lambda-cyhalothrin. Alternate use of these insecticides can minimize resistance problem in this pest.
- Development of resistance to malathion, endosulfan and fenvalerate by continuous use of these insecticides against *P. xylostella* has been found to make the pest biologically superior by having shorter development and with no adverse affect on fecundity and survival of eggs, larvae and pupae. Biological superiority of this pest may create serious problem to vegetable growers in the state.

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* Original not seen

DEPARTMENT OF ENTOMOLOGY
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Title of the Thesis	:	**Development of resistance to some insecticides in diamondback moth, *Plutella xylostella* (L.)**
Name of Student	:	**Ramesh Lal**
Admission No.	:	**A-98-40-04**
Major subject	:	**Entomology**
Minor subject(s)	:	**(i) Plant Pathology (ii) Chemistry**
Degree	:	**Ph.D.**
Month and year of submission of thesis	:	**May, 2003**
Total pages in the thesis	:	**180**
Number of words in abstract	:	**353**
Major advisor	:	**Dr. Jitender Kumar sharma**

ABSTRACT

Toxicity of malathion, endosulfan and fenvalerate to third instar larvae of diamondback moth, *Plutella xylostella* (L.) collected from thirteen different vegetable growing localities of Himachal Pradesh during April-May, 2000 was determined by using direct spray method of bioassay. Comparison of LC_{50} values of malathion, endosulfan and fenvalerate to different populations of *P. xylostella* showed that these populations did not differ significantly among themselves for their susceptibility to these insecticides. The LC_{50} values of malathion, endosulfan and fenvalerate varied from 0.0231 to 0.0491, 0.0252 to 0.0386 and 0.00708 to 0.01070 per cent, respectively. The average LC_{50} values of malathion, endosulfan and fenvalerate to the 3rd instar larvae were 0.0377, 0.0310 and 0.00807 per cent, respectively. Resistance ratios calculated on the basis of LC_{99} value and recommended field doses (0.05% for both malathion and endosulfan, 0.01% for fenvalerate) showed that these ratios for malathion, endosulfan and fenvalerate varied from 13.72 to 29.72, 07.76 to 21.08 and 20.20 to 36.20 when tested against 3rd instar larvae.

Selection of 3rd instar larvae of *P. xylostella* for resistance to malathion, endosulfan and fenvalerate by applying a selection pressure of 60-80% kill in every generation, resulted into 27.32, 29.96 19.06 times resistance to respective insecticides after 14th generation (parental, G_1 to G_{13}) of selection in comparison to the non-selected strain. The rate of development of resistance to all the three test insecticides was found to be little slower in the initial generations of selection.

The resistant strain exhibiting 27.32 times resistance to malathion vis-a-vis the susceptible strain showed cross- resistance which was of the order of: fenvalerate (2.15x), endosulfan (3.61x), monocrotophos (2.30x) cypermethrin (1.37x) and lambda-cyhalothrin (1.43).

Cross-resistance shown by endosulfan-resistant strain (29.96x) was: malathion (2.26x), cypermethrin (1.07x), fenvalerate (1.71x), monocrotophos (1.38x) and lambda-cyhalothrin (1.15x). Cross-resistance shown by fenvalerate-resistant strain (19.06x) was: malathion (1.68x), cypermethrin (2.28x), monocrotophos (1.15x), endosulfan (2.91x) and lambda-cyhalothrin (1.29x).

Comparison of biological characteristics of the strains resistant to malathion, endosulfan and fenvalerate vis-a-vis susceptible strain (without selection pressure) showed that resistant strains had become biologically superior by having shorter developmental period and with no adverse affect on fecundity and survival of eggs, larvae and pupae.

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