CERTIFICATE

Mr. N. Mallikharjuna Rao has satisfactorily prosecuted the course of research and that the thesis entitled **"STUDIES ON ASSESSMENT AND MANAGEMENT OF INSECTICIDE RESISTANCE IN RICE BROWN PLANTHOPPER, *Nilaparvata lugens* (Stal)"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

Date: **(P. SATYANARAYANA REDDY)**
Chairperson

CERTIFICATE

This is to certify that thesis entitled **"STUDIES ON ASSESSMENT AND MANAGEMENT OF INSECTICIDE RESISTANCE IN RICE BROWN PLANTHOPPER, *Nilaparvata lugens* (Stal)"** submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Agriculture of the Acharya N. G. Ranga Agricultural University, Hyderabad, is a record of the bonafide original research work carried out by **Mr. N. Mallikharjuna Rao** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

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I, **N. MALLIKHARJUNA RAO** hereby declare that the thesis entitled **"STUDIES ON ASSESSMENT AND MANAGEMENT OF INSECTICIDE RESISTANCE IN RICE BROWN PLANTHOPPER, *Nilaparvata lugens* (Stal)",** submitted to the **Acharya N. G. Ranga Agricultural University** for the degree of **Doctor of Philosophy in Agriculture** in the major field of **Entomology** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

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Date: **I. D. No. BAD 07- 05**

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Date:

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LIST OF SYMBOLS AND ABBREVIATIONS USED

a	:	Intercept
AchE	:	Acetyl Cholinesterase
a. i.	:	Active Ingredient
b	:	Slope
BHC	:	Benzene Hexa Chloride
BPMC	:	Butyl Phenyl Methyl Carbamate
BPH	:	Brown Planthopper
cm	:	Centimetre
CD (0.05)	:	Critical Difference at 5 per cent probability
CRD	:	Complete Randomized Design
DAT	:	Days After Treatment
DDT	:	Dichloro Diphenyl Trichloro ethane
DEF	:	*S'S'S'* – tributyl phosporotrithioate
DEM	:	Diethyl Maleate
EC	:	Emulsifiable Concentration
E.G.	:	East Godavari
et al.	:	And Others
etc.	:	et cet-era
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
FL	:	Fiducial Limit
GABA	:	Gamma Amino Butyric Acid
g	:	Gram
G	:	Granules
GLH	:	Green Leafhopper
GST	:	Glutathione S-Transferase
ha	:	Hectare
ha^{-1}	:	Per Hectare
HAT	:	Hours After Treatment
i.e.	:	that is
IGR	:	Insect Growth Regulator
IRM	:	Insecticide Resistance Management
Kg	:	Kilogram
KNR	:	Karimnagar
l	:	Litre
LC	:	Lethal Concentration
lcp	:	Log Concentration Probit
LD	:	Lethal Dose
Ltd.	:	Limited

m	:	Metre
MFO	:	Mixed Function Oxidase
M.ha.	:	Million Hectare
mg	:	Milligram
ml.	:	Milli litre
MLP	:	Maximum Likelihood Programme
mm	:	Milli Metre
m^2	:	Square Metre
M.T	:	Million Tonnes
MTMC	:	3-methylphenyl-N-methyl-carbamate
MIPC	:	2-isopropylphenyl N-methyl-carbamate
nAChR	:	Nicotinic Acetylcholine Receptor
No.	:	Number
NS	:	Non Significant
Ops	:	Organophosphates
PBO	:	Piperonyl Butoxide
PSMO	:	Poly Substrate Mono Oxygenase
ppm	:	Parts Per Million
Pvt.	:	Private
q	:	Quintals
RH	:	Relative Humidity
RF	:	Resistance Factor
SBPH	:	Small Brown Planthopper
SC	:	Soluble Concentrate
SEm.	:	Standard Error of Mean
SF	:	Synergistic Factor
SG	:	Soluble Granules
Sig.	:	Significant
SL	:	Soluble Liquid
SP	:	Soluble Power
sp.	:	Species
SR	:	Synergistic Ratio
SUS.	:	Susceptible
t	:	Tonnes
TBPT	:	Triphenyl Phosphoro Trithioate
TPP	:	Tri phenyl Phosphate
U.K.	:	United Kingdom
viz.,	:	Namely
WBPH	:	Whitebacked Planthopper
WG	:	Wettable granules

W.G.	:	West Godavari
WP	:	Wettable Powder
WHO	:	World Health Organization
x	:	Folds
@	:	At the rate of
^{o}C	:	Degrees Centigrade (or) Celcius
&	:	And
γ	:	Gamma
χ^2	:	Chi-square
>	:	Greater than
<	:	Less than
μg	:	Micro gram
μl	:	Micro litre
%	:	Per cent
$\pm$	:	Plus or minus
+	:	Plus

ABSTRACT

Name of the Author	:	**N. MALLIKHARJUNA RAO**
Title of the Thesis	:	**"Studies on assessment and management of insecticide resistance in rice brown planthopper, *Nilaparvata lugens* (Stal)"**
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Experiments were conducted in the laboratory of the Department of Entomology, Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, during 2008-09 and 2009-10 to determine the degree of resistance acquired by Rice brown planthopper, *Nilaparvata lugens* (Stal) to eight insecticides, the occurrence of PBO and TPP suppressible metabolic resistance, the possibility of managing resistance with selected novel insecticides and the influence of insecticide resistance on the biology of *N. lugens.*

The BPH populations of the three districts *viz.*, West Godavari, East Godavari and Karimnagar differed in the degree of resistance acquired by them to each of the eight test insecticides. The West Godavari strain of *N. lugens* was found to be 3.63 and 3.16; 3.01 and 3.07; 2.80 and 2.79; 2.22 and 2.30; 1.39 and 1.69; 1.50 and 1.36; 46.66 and 47.14; 13.11 and 12.94 folds resistant at LC_{50} and 2.60 and 2.52; 1.31 and 1.49; 1.10 and 1.28; 1.40 and 1.40; 1.06 and 1.50; 1.23 and 1.11; 9.4 and 14.66; 2.84 and 2.51 folds resistant at LC_{90} to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam during 2008-09 and 2009-10, respectively compared to susceptible strain.

The East Godavari strain of *N. lugens* acquired 3.53 and 3.02; 2.37 and 2.50; 2.42 and 2.36; 1.98 and 2.04; 1.41 and 1.44; 1.40 and 1.15; 28.75 and 34.76; 8.51 and 7.82 fold resistance at LC_{50} and 2.87 and 2.66; 1.07 and 1.31; 0.00 and 1.19; 1.35 and 1.38; 1.12 and 1.26; 1.27 and 1.02; 6.25 and 8.38; 3.73 and 4.05 fold resistance at LC_{90} to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam during 2008-09 and 2009-10, respectively compared to susceptible strain.

The Karimnagar strain of *N. lugens* showed 2.11 and 2.00; 2.34 and 2.52; 0.00 and 1.31; 1.93 and 2.12; 1.28 and 1.33; 1.10 and 1.03; 36.66 and 41.90; 12.70 and 11.41 fold resistance at LC_{50} and 1.26 and 1.25; 1.08 and 1.31; 0.00 and 0.00; 1.51 and 1.53; 1.06 and 1.30; 1.01 and 1.02; 8.05 and 13.38; 2.70 and 1.98 fold resistance at LC_{90} to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam during 2008-09 and 2009-10, respectively compared to susceptible strain.

The synergistic effect of PBO with the test insecticides *viz.*, endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam revealed that the relatively resistant West Godavari strain of *N. lugens* recorded the synergistic ratios of 10.08 and 9.66; 13.88 and 11.43; 18.82 and 13.45; 15.95 and 11.52; 2.41 and 1.55; 3.75 and 1.37; 3.2 and 6.19; 3.46 and 1.97 at LC_{50} and LC_{90} levels, respectively during 2008-09. While, the corresponding values of synergistic ratios during 2009-10 were 8.48 and 11.42; 19.81 and 10.91; 21.35 and 17.20; 15.69 and 9.92; 2.44 and 1.73; 3.21 and 1.88; 2.67 and 5.89; 3.48 and 1.98 at LC_{50} and LC_{90} levels, respectively.

The synergistic effect of TPP with the test insecticides *viz.*, endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam revealed that the relatively resistant West Godavari strain of *N. lugens* recorded the synergistic ratios of 6.66 and 7.41; 16.13 and 10.62; 14.22 and 11.60; 1.28 and 1.14; 1.59 and 1.33; 1.80 and 1.65; 1.09 and 1.12; 1.03 and 1.03 at LC_{50} and LC_{90} levels, respectively during 2008-09. While, the corresponding values of synergistic ratios during 2009-10 were 6.16 and 8.61; 14.2 and 9.75; 12.49 and 12.94; 1.29 and 1.22; 1.72 and 1.51; 1.95 and 1.34; 1.08 and 1.21; 1.24 and 1.19 at LC_{50} and LC_{90} levels, respectively. The synergism with TPP was more in monocrotophos followed by acephate, endosulfan, ethofenprox, fenobucarb, phosphamidon, imidacloprid and thiamethoxam,

Among the novel insecticides tested, buprofezin was found to be the best alternative insecticide for managing the resistant strain followed by pymetrozine and imidacloprid + ethiprole and ethiprole alone.

The BPH populations of different districts recorded significantly more egg periods compared to the susceptible population. But no significant differences were observed in other biological parameters *viz.*, number of progeny, total nymphal period, adult longevity, pre oviposition period, oviposition period and total life cycle.

Chapter I

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food crop of India, providing 30 per cent of caloric requirement for more than 70 per cent of Indian population. It occupies highest area among all the crops grown in the country. Within the country, rice accounts for 35.4 per cent of area and 42.9 per cent of total food grain production, 43.5 per cent of the area and 45.9 per cent of the total cereal production in the country (Shobha Rani *et al*., 2010).

Rice is ravaged by various pest problems from seedling stage to maturity. About 200 insect species have been reported to damage rice crop in India. Among these, 20 species of insects have been found to be serious causing more than 50 per cent yield loss (Arora and Dhaliwal, 1996). Among different insect pests attacking rice crop, planthoppers constitute one of the most important group causing substantial yield losses. Among the planthoppers, the Brown Planthopper (BPH), *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae), is an economically important insect pest of rice (Heinrichs, 1994). Both nymphs and adults of the BPH suck plant sap from phloem cells resulting in “hopper burn” symptoms, and it can cover large patches in rice fields under heavy pest pressure.

In early seventies and eighties, organophosphates like monocrotophos and acephate, carbamates like carbaryl and fenobucarb and ether derivatives like ethofenprox were extensively used in India as well as other countries (Jhansilakshmi *et al*., 2010a). As a result, these hopper pests became resistant to these insecticides in Japan, Taiwan, China and Philippines and insecticide resistance has been reported to be in incipient stage in India (Sarupa *et al*., 1998 and Padma kumari *et al*., 2002).

Since 1997, neonicotinoids or chloronicotinyles such as imidacloprid, thiamethoxam and clothianidin were extensively utilized for suppressing the hopper populations in China, India, Taiwan, Japan and Korea and there are already reports of resistance development (Liu *et al*., 2003a., Nauen and Denholm, 2005 and Jhansilakshmi *et al*., 2010a). Resistance to imidacloprid has been reported in a range of other insect species including field populations and laboratory selected strains (Zhao *et al.,* 1995., Prabhaker *et al.*, 1997., Kevin *et al.*, 2008 and Matsumura *et al.*, 2008).

To manage the insecticide resistance, synergists can be used as an additional tool in insect pest management. The synergists increase the lethality of insecticides by inhibiting insecticide detoxifying enzymes and they can be used as tools for elucidating resistance mechanisms (Raffa and Priester, 1985).

The major insecticide resistance mechanism reported in BPH collected from rice is elevation of one or more esterases (Chen and Sun, 1994). Studies on these lines can help in understanding the different mechanisms that are involved in conferring resistance to particular compound, their relative importance and frequencies in field populations in different parts of the country.

Judicious use of insecticides and alternation of chemicals with different mode of action are suggested to reduce insecticide resistance (Mehrotra, 1992). So, the newer insecticide molecules with diversified mode of action against hoppers will significantly play a vital role in the insecticide resistance management.

The biological characters are subjected to change due to insecticidal selection. The evolution and spread of insecticide resistance is influenced by biological and genetic factors (Georghiou and Taylor, 1977).

Hence, keeping the above problems of insecticide resistance and possibilities of Insecticide Resistance Management (IRM) in view, "Studies on assessment and management of insecticide resistance in rice brown planthopper, *Nilaparvata lugens* (Stal)" were undertaken with the following objectives.

1. To assess the degree of insecticide resistance acquired by the field populations of rice brown planthopper, *Nilaparvata lugens* (Stal) in certain rice growing areas of Andhra Pradesh.

2. To study the influence of synergists on insecticide resistance.

3. To explore the possibility of management of insecticide resistance in *Nilaparvata lugens* (Stal) with certain insecticides having novel mode of action.

4. To study the effect of insecticide resistance on biology of *Nilaparvata lugens* (Stal).

Chapter II

REVIEW OF LITERATURE

The literature pertaining to "Studies on assessment and management of insecticide resistance in rice brown planthopper, *Nilaparvata lugens* (Stal)" has been reviewed and presented in this chapter.

2.1 DISTRIBUTION AND LOSSES CAUSED BY PLANTHOPPERS

Among the insect pests attacking the rice crop, planthoppers constitute an important group. Brown planthopper, *Nilaparvata lugens* (Stal) (BPH) and whitebacked planthopper, *Sogatella furcifera* (Horvath) (WBPH) are very serious pests in several rice growing tracts in India. Planthoppers have become a threat to rice production not only in India, but also in South East Asian countries. Out breaks of BPH and Whitebacked planthoppers have caused serious concern in Punjab and Haryana (Virk and Sarao, 2010).

The WBPH, occurring in northern states like Haryana and Punjab alone has become a regular pest in several rice growing tracts in India (Krishnaiah *et al.*, 2004 and causes 35 to 90 per cent yield loss (Sidhu, 1979).

Farmers continue to depend on the use of insecticides for the management of planthoppers in many endemic areas in the country. However, the control of planthoppers by insecticides is becoming increasingly difficult even in the resistant rice varieties due to the development of insecticide resistance (Pathak and Heinrichs, 1982, Joshi *et al.*, 1992 and Matsmura *et al*., 2009).

2.2 INSECTICIDE RESISTANCE IN ARTHROPODS

The most quoted definition of resistance is that of the World Health Organization (W.H.O) which is; "Resistance to insecticides is the development of an ability in a strain of insects to tolerate doses of toxicant which would prove lethal to the majority of individuals in normal populations of the same species" (O' Brien, 1967).

The instance of insecticide resistance was first noticed in San Jose scale, *Quadraspidiotus perinicious* (Comstock) in 1908 against lime sulphur in Washington State in the USA (Melander, 1914). The number of resistant pests had reached to 504 by the end of 1989 (Georghiou and Tajeda, 1991). Of these resistant species, 59.0 per cent were of agricultural importance, 38.0 per cent were of medical and veterinary importance and 3.0 per cent are of natural enemies (Georghiou, 1986).

2.3 INSECTICIDE RESISTANCE IN INDIA

The occurrence of pesticide resistance in India was first noticed in insects of public health importance. The first report of dichloro diphenyl trichloro ethane (DDT) resistance in mosquitoes came in 1952 in *Culex fatigans* Wiedeman, a transmitter of filaria from U. P and Bombay. Resistance to agricultural pests was first reported on Singhara beetle, *Galerucella birmanica* (Jacoby) from Delhi against DDT and benzene hexachloride (BHC) (Pradhan *et al.*, 1963). Next insect pest of agricultural importance to develop resistance to pesticides was the tobacco caterpillar, *Spodoptera litura* (Fab.) against BHC on cauliflower (Srivastava and Joshi, 1965).

2.4 GLOBAL STATUS OF INSECTICIDE RESISTANCE IN RICE PLANT-HOPPERS

The literature in respect of resistance acquired by rice planthoppers BPH, WBPH and Small Brown Planthopper (SBPH) to various insecticides belonging to different groups *viz*., organochlorines, organophosphates, carbamates, synthetic pyrethroids, neonicotinoids and phenyl pyrazole from India and abroad was reviewed in the context of objectives of present investigations. In addition, list of reports (Table 2.1) on insecticide resistance acquired by BPH in India and abroad was also included.

2.4.1 Insecticide Resistance in Rice Brown Planthopper, *N.lugens* (Stal)

2.4.1.1 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Organochlorine Insecticides

Nagata (1982) studied development of insecticide resistance in *N. lugens* in Japan. His studies revealed that resistance in BPH to BHC was closely associated with its long distance migration. The quick establishment of an HCH-resistant population by insecticide pressure, its extinction during the winter and the subsequent appearance of susceptible migrants in the following year was evident from the fluctuating levels of resistance in individuals taken from rice fields in Japan at different times of the year. A gradual increase in the level of resistance was observed when data from 1976 was compared with those from 1967.

Tang *et al*. (1982) conducted survey on the susceptibility of *N. lugens* collected from different areas of Zhejiang province of China to γ BHC. The data showed that the autumnal generation was 4.7 fold resistant to γ BHC as compared with LD_{50} of the immigrant summer generation.

Endo *et al.* (1988a) studied the susceptibility of *N. lugens* to various insecticides using population collected in Japan in 1980 and 1987. A comparison of the results obtained in these experiments with previous data collected in 1967 showed that the susceptibility of *N. lugens* to organophosphates in 1987 was greater than 1980. The susceptibility to p, p-DDT decreased with time, but susceptibility to lindane was almost same as in 1967.

2.4.1.2 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Organophosphorous Insecticides

Chung *et al*. (1981) studied the cross-resistance pattern for malathion-resistant strain of BPH and found that resistance ratios were 1183 for malathion and 82 for parathion methyl.

Chung *et al*. (1982) observed 1183-fold resistance for malathion compared to the susceptible strain in Taiwan.

Ozaki and Kassai (1982) reported that the field populations of *N. lugens* collected from Kagawa prefecture of Japan in 1979 were highly resistant to fenthion (30 to 32 fold), fenitrothion (22 to 23 fold), cyanofenphos (145 to 423 fold) and malathion (20 to 35 fold). The development of carbamate resistance was slower than that of resistance to organophosphates fenthion, fenitrothion or malathion.

Mochida and Basilio (1983) reported that insecticide induced mortality among populations of the *N. lugens* collected from fields of International Rice Research Institute (IRRI), Philippines was much lower than that among greenhouse populations. The development of resistance among the field populations was favoured by the applications of a mixture of chlorpyriphos and BPMC since 1978 and that of acephate since 1981.

Tranter and Emden (1984) compared susceptibility of 8 populations of BPH of United Kingdom (U.K) to organophosphorus insecticides and reported that the Queensland strain was the most susceptible while a strain from Japan showed high level of resistance to malathion.

Kassai and Ozaki (1984) compared the LD_{50} values of laboratory selected BPH with carbaryl or propoxur for 12 successive generations in Japan with initial LD_{50} levels of the parent population. The carbaryl-selected strain developed a 4 fold resistance to carbaryl, 2 to 4 fold resistance to most of the carbamates tested and also to the organophosphorus insecticides, *viz.*, dimethylvinphos, tetrachlorovinphos, monocrotophos, propaphos, fenthion, pyridaphenthion, disulfoton, malathion, dimethoate, phenthoate and mecarbam while the susceptibility to diazinon, cyanofenphos and isoxathion remained unchanged.

Sun *et al.* (1984a) reported that populations of *N. lugens* collected in Taiwan were found to possess a high resistance to malathion. Wang and Ku (1984) observed 8.4 fold resistance to carbaryl and high level of resistance to monocrotophos in the BPH population of Taiwan. Wang *et al*. (1988a) studied the local variations in resistance to the insecticides carbaryl, carbofuran, malathion and monocrotophos between 1982 and 1984 in BPH of central Taiwan. The ratio of maximum to minimum LC_{50} varied from 2.4 to 15.5 fold for BPH collected during the autumn in 1982-84, but only 2.3 to 2.9 fold in surveys carried out during the spring crop of 1984.

Ghorpade (1990) studied 3 strains of BPH for tolerance to 5 insecticides and stated that Niigata strain from Japan showed the broadest range of resistance to malathion (5 fold) and monocrotophos (6 fold). The Philippines strain showed intermediate tolerance to the test insecticides. Ghorpade (1993) studied tolerance levels in BPH strains collected from Japan, Philippines, Australia, Indonesia and Sri Lanka against monocrotophos and malathion and reported that the Japanese and Australian strains were the most susceptible to above insecticides.

Hirai (1994) reviewed the status of insecticide susceptibility to carbaryl, malathion and propaphos for immigrant *N. lugens* on rice in Nagasaki, Kyushu, Japan. The BPH had developed resistance to organophosphates in the second half of the 1970's and had remained moderately resistant from the beginning of the 1980's to 1993.

Sarupa *et al*. (1998) reported that the Godavari strain of BPH recorded moderate resistance ratios for chlorpyriphos (2.20), phosphamidon (1.89), carbaryl (1.5), monocrotophos (1.35) and quinalphos (1.244).

Hemingway *et al*. (1999) reported that BPH populations of Batalgoda, Sri Lanka and Sulawesi, Indonesia showed low (2-5 folds) levels of resistance to malathion and propoxur.

Xaofei *et al*. (2001) determined the insecticide susceptibility of BPH collected from China and Japan in 1977 by topical application. The insecticide susceptibility of BPH was not much different among the populations from Nagasaki (South West Japan), Hangzhou (Zhejiang, China) and Jhinghong (Yunnan, China). LD_{50} of BPH was 67-130 µg/g for malathion, 51-93 µg/g for fenitrothion and 57-94 µg/g for DDT. It was also observed that organophosphate susceptibility was not different between BPH population collected in 1992 and 1997.

Yoo *et al*. (2002) reported that highly resistant strains of the brown planthopper were obtained after 30 generations of laboratory selection by carbofuran or fenobucarb in Korea. This strain showed 6-7 times more resistance to diazinon.

Krishnaiah *et al*. (2002) studied the resistance development in *N. lugens* under greenhouse conditions by exposing the insects to LC_{70} to LC_{80} concentrations of a recommended insecticide monocrotophos and the most effective neem formulation NG 4 once in each generation continuously for 26 generations. The results on resistance development and cross resistance pattern revealed that monocrotophos selected strain of *N. lugens* showed slight resistance (1.16 to 2.41) to monocrotophos, BPMC and cartap hydrochloride but moderate cross resistance to ethofenprox (2.04 to 397), NG 4 (3.0 to 3.97) and imidacloprid (2.76 to 5.38 times).

Liu *et al*. (2002a) reported that the resistant strain of brown planthopper selected for methamidophos resistance displayed 43.74 fold resistance to methamidophos and also had cross resistance to malathion and diazinon.

Sujatha and Regupathy (2003) conducted dose response bioassays in BPH by using phosphamidon selected strains. The resistance ratios obtained were 2.2, 1.7 and 1.3 for phosphamidon based on LD_{50}, LD_{90}, and LD_{99} values, respectively.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field of populations of BPH during 2006 and reported that the BPH in Godavari delta continued to remain susceptible to organophosphates like acephate and monocrotophos.

2.4.1.3 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Carbamate Insecticides

Lin and Sun (1978) reported that the insecticide resistance level of field collected *N. lugens* to 2-isopropylphenyl N-methyl-carbamate (isoprocarb-MIPC) and 3-methyl phenyl methyl carbamate (MTMC) decreased slightly after rearing in the laboratory for 13 generations. One of field collected strains developed 6.1 times more resistance after 6 generations.

Heinrichs and Tetangco (1978) reported that a field strain of *N. lugens* at IRRI, Philippines exposed to carbofuran for several years had developed resistance to the compound. Both sexes were seven times as resistant to carbofuran as compared to a greenhouse strain not exposed to insecticides and 2-5 times as resistant as the greenhouse strain to other insecticides used to varying extents on the IRRI farm, including monocrotophos and isoprocarb.

Chung *et al*. (1981) studied the cross resistance pattern for malathion-resistant strain of BPH and found a resistance ratio of 22 for isoprocarb, while the corresponding ratio for the isoprocarb resistant strain was 41.

Kilin *et al*. (1981) compared the susceptibility of immigrant population of BPH in Japan in 1976 with those obtained in 1967 and the LD_{50} value for MTMC, Carbaryl and isoprocarb had increased 10-fold.

Chung *et al*. (1982) made studies in Taiwan, in which an isoprocarb resistant strain selected for 16 generations developed 41-fold resistance. Ozaki and Kassai (1982) reported that the development of resistance to carbamate insecticides in the field populations of *N. lugens* collected from Kagawa prefecture of Japan in 1979 was slower than that of resistance to organophosphates fenthion, fenitrothion or malathion.

Heong (1983) reported that *N. lugens* populations in Malaysia have become more resistant to MTMC between 1977 and 1982.

Kassai and Ozaki (1984) compared the LD_{50} values of laboratory selected BPH with carbaryl and propoxur for 12 successive generations in Japan with initial LD_{50} levels of the parent population. The carbaryl-selected strain developed a 2 to 4 fold resistance to most of the carbamates and the propoxur-selected strain acquired 2 to 4 fold resistance to the other carbamates tested.

Wang and Ku (1984) observed that resistance to carbofuran increased 14.8 fold in the BPH population of Taiwan. Fabellar and Mochida (1985) reported that field collected populations of Philippines which had prior exposure to insecticides showed significant level of resistance to BPMC (Fenobucarb) but did not appear to have developed resistance to carbaryl, carbofuran or MTMC (metolcarb) as compared to greenhouse populations.

Wang *et al*. (1988a) studied the local variations in resistance to the insecticides carbaryl, carbofuran, malathion and monocrotophos between 1982 and 1984 in rice BPH of central Taiwan. The ratio of maximum to minimum LC_{50} varied from 2.4 to 15.5 fold for BPH collected during the autumn in 1982-84, but only 2.3 to 2.9 fold in surveys carried out during the spring crop of 1984.

Ghorpade (1990) studied 3 strains of BPH for tolerance to carbamates and stated that Niigata strain (Ns) from Japan showed the broadest range of resistance to MTMC (9 fold) and carbofuran (2 fold). The Philippines strain showed intermediate tolerance to the test insecticides. Ghorpade (1993) studied tolerance levels in BPH strains collected from Japan, Philippines, Australia, Indonesia and Sri Lanka against carbofuran, and reported that the Japanese and Australian strains were the most susceptible to the this insecticide.

Hirai (1994) reviewed current status of insecticide susceptibility to BPMC (fenobucarb), MTMC (metolcarb), carbofuran, for immigrant *N. lugens* on rice in Nagasaki, Kyushu, Japan. The pest had developed resistance to carbamates in the second half of the 1970's and had remained moderately resistant from the beginning of the 1980's to 1993.

Sarupa *et al*. (1998) studied the insecticide resistance in field populations of *N. lugens* in Godavari delta of Andhra Pradesh and observed moderate resistance ratios to BPMC (2.30) and carbofuran (1.247).

Yoo *et al*. (2002) reported that highly resistant strains of the brown planthopper were obtained after 30 generations of laboratory selection by carbofuran or fenobucarb in Korea. Topical LD_{50} value increased 93-101 times for fenobucarb and 51-68 times for carbofuran.

Krishnaiah *et al*. (2002) studied the resistance development in *N. lugens* under greenhouse conditions by continuously exposing the insects to LC_{70} to LC_{80} concentrations of a recommended insecticide monocrotophos and the most effective neem formulation NG 4 once in each generation continuously for 26 generations. The results on resistance development and cross resistance pattern revealed that NG 4 strain developed 1.98 to 2.15 times resistance to NG 4 and low cross resistance (1.11 to 1.96 times) to monocrotophos, ethofenprox, BPMC, cartap hydrochloride and imidacloprid. However, monocrotophos selected strain of BPH showed slight resistance (1.16 to 2.41) to monocrotophos and BPMC.

Liu *et al*. (2002a) reported that the resistant strain of brown planthopper selected for methamidophos resistance had cross resistance to isoprocarb, fenobucarb and ethofenprox, but no cross resistance to fenvalerate and imidacloprid.

Nagata and Kamimuro (2003) conducted experiments to know the insecticide resistance in migrating BPH populations of China, Japan, Malaysia and Vietnam. Results obtained in the resistance monitoring trial conducted during 2000 revealed considerable difference in topical LD_{50} among the three sites in China. The Anqing population was definitely less susceptible than those in other two sites (Dongtai and Gullin). Vietnam data (average of the four monitoring sites) along the Red-river delta areas when compared with their 1987-1992 data, 4.4 times increase for fenobucarb

(BPMC), 7.3 times increase for carbofuran and 12 times increase for isoprocarb (MIPC) were observed and coincided with the data of the Japan population except for those of imidacloprid.

Sujatha and Regupathy (2003) conducted dose response bioassays with BPH by using carbofuran selected strain. The resistance ratios obtained were 4.0, 2.3 and 1.4 for carbofuran based on LD_{50}, LD_{90}, and LD_{99} values, respectively.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of BPH collected from Godavari delta during 2006 and reported that the BPH exhibited low to moderate resistance to fenobucarb.

2.4.1.4 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Synthetic Pyrethroid Insecticides

Chung *et al*. (1981) studied the cross resistance pattern for malathion-resistant strain of BPH and found that resistance ratios were 171 for permethrin and 5 for fenvalerate. Chung *et al*. (1982) conducted studies in Taiwan, in which a malathion-resistant strain of *N. lugens* developed by continuous selection of a field strain for 9 generations in the laboratory, gained 1183-fold resistance compared to the susceptible strain. An isoprocarb resistant strain selected similarly for 16 generations developed 41-fold resistance. Both were equally and significantly resistant to propoxur and permethrin but remained susceptible to fenvalerate.

Hemingway *et al*. (1999) collected two sibling species of *N. lugens* from cultivated rice and two from the wild grass *Leersia hexandra*. Strains of the rice-associated species of *N. lugens* were exposed to selection pressure over an extended period, while the Leersia-associated species had little prior insecticide exposure. The rice associated species from Batalgoda, Sri Lanka and Sulawesi, Indonesia both showed 2-17 fold resistance to permethrin at the LD_{50} level compared with the *Leersia*-associated species from Bogor, Indonesia.

2.4.1.5 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Non Ester Synthetic Pyrethroids

Xaofei *et al*. (2001) determined the insecticide susceptibility of BPH collected from China and Japan in 1977 by topical application. The insecticide susceptibility of BPH was not much different among the populations from Nagasaki (South West Japan), Hangzhou (Zhejiang, China) and Jhinghong (Yunnan, China). LD_{50} of BPH was 0.78-1.2 µg/g for ethofenprox.

Krishnaiah *et al*. (2002) reported that monocrotophos selected strain of *N. lugens* showed moderate cross resistance to ethofenprox (2.04 to 397). These observations indicated the potential for cross resistance of the insect to more recent insecticides like ethofenprox and imidacloprid with prior exposure to monocrotophos.

Liu *et al*. (2002a) reported that the resistant strain of brown planthopper selected for methamidophos had cross resistance to ethofenprox, but no cross resistance to fenvalerate.

2.4.1.6 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Neonicotinoid Insecticides

Liu *et al*. (2002b) from Nanjing, China determined the base line susceptibility of females, males and different nymphal instars of BPH to imidacloprid by using root dipping method. The results of the neonicotinoid resistance monitoring in *N. lugens* in three areas of China *viz*., Guilin, Anquing and Dongtai showed that these populations had developed low level of resistance to imidaclopird in all three areas. However, the resistance of the hopper in Anquing and Dongtai was a little higher than the level in Guilin populations.

Nagata *et al*. (2002) studied the insecticide resistance in long-range migrating rice BPH in Japan, China (3 locations) and Malaysia. The LD_{50} for the Japan BPH coincided with those for two China populations, but one of the China populations gave remarkably larger LD_{50} for imidacloprid.

Krishnaiah *et al*. (2002) studied the resistance development in *N. lugens* under greenhouse conditions by continuous exposure of the insects to LC_{70} to LC_{80} concentrations of a recommended insecticide monocrotophos and the most effective

neem formulation NG 4 once in each generation continuously for 26 generations. The results on resistance development and cross resistance pattern revealed that NG 4 strain developed low and monocrotophos selected strain showed moderate cross resistance to imidacloprid (2.76 to 5.38 times).

Liu *et al*. (2003a) collected the field population of BPH and selected for imidacloprid resistance in the laboratory. The resistance was increased by 11.35 times in 25 generations and the resistance ratio reached 72.83 compared with a laboratory susceptible strain. The selected resistant strain showed obvious cross-resistance to all the acetylcholine receptor targeting insecticides tested (monosultap 1.44-fold, acetamiprid 1.61-fold, imidacloprid homologues JS599 2.46-fold and JS598 3.17 fold), but not to others.

Fukuda *et al*. (2007) conducted resistance studies in BPH in Japan. The *N. lugens* population that migrated to Kagoshima prefecture in 2005-06 was compared with the *N. lugens* population that migrated to Nagasaki prefecture in 1999. The level of susceptibility to imidacloprid appeared to be more pronounced in the Kagoshima population than in the Nagasaki population.

Kevin *et al*. (2008) investigated the extent of neonicotinoid insecticide resistance in BPH collected from China, India, Indonesia, Malaysia, Thailand and Vietnam during 2005 and 2006 and reported that ten samples collected during 2005 were found to be susceptible to imidacloprid, but two late-season samples from India showed reduced mortality at both diagnostic doses. Matsumura *et al*. (2008) reported that insecticide resistance in BPH against imidacloprid occurred in East Asia and Indo-China, but not in the Philippines. Wang *et al*. (2008a) studied the neonicotinoid resistance in rice BPH in China and reported that 16 populations from six provinces quickly developed resistance with resistance ratios ranging from 79 to 811. The data collected in 2006 revealed slight decrease in resistance levels in 12 populations collected from seven different provinces (RR=107-316).

Wen *et al*. (2009) stated that the BPH of field populations of China had developed moderate to high level of resistance to imidacloprid. Further, they reported that the imidacloprid resistant hoppers did not show cross resistance to all the neonicotinoid insecticides and high level of imidaclopird resistance in BPH was very

unstable. Wang *et al*. (2009) studied the insecticide resistance levels in field populations of BPH in China. He reported that the field populations of BPH have developed variable resistance to neonicotinoids, with a high or extremely high resistance level to imidacloprid, a low and medium resistance level to imidaclothiz and thiamethoxam, respectively, and no resistance to dinotefuran and nitenpyram.

Liang *et al*. (2010) monitored the susceptibility of BPH to imidacloprid from 2006 to 2008 in 7 field populations collected in China. The results showed that the collected population showed resistance to imidacloprid with resistance index varying from 98.89 to 389.19, 69.00 to 153.33 and 56.32 to 116.89, respectively compared with the susceptible colony from year 2006 to 2008 although the resistance level decreased in three years.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of BPH during 2004 and 2006. During 2004, the resistance ratios obtained for imidacloprid, thiamethoxam and clothianidin were 35.1, 10.8, and 4.9, respectively. During 2006, BPH in Godavari delta exhibited increased order of resistance to neonicotinoids with RR values of 64.9, 17.9 and 13.2 for imidacloprid, thiamethoxam and clothianidin, respectively.

2.4.1.7 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Chitin Synthesis Inhibiting Insecticides

Zhuang and Shen (2000) reported that the BPH collected from Anquing and Jiangpu of China in 1996 and Nanning in 1997 had developed low level of resistance to buprofezin.

Liang *et al*. (2010) monitored the susceptibility of BPH to buprofezin from 2007 to 2008 in 7 field populations collected in China. The results showed that the collected population showed resistance to buprofezin with resistance index from 13.39 to 41.06 in 2007 and 6.94 to 20.44 in 2008.

2.4.1.8 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to Phenyl Pyrazole Insecticides

Fukuda *et al*. (2007) conducted resistance studies in BPH in Japan. The *N. lugens* population that migrated to Kagoshima prefecture in 2005-06 was compared with the *N. lugens* population that migrated to Nagasaki prefecture in 1999. The level of susceptibility to fipronil did not significantly vary between the populations.

Liang *et al*. (2010) monitored the susceptibility of BPH to fipronil from 2007 to 2008 in 7 field populations collected in China. The results showed that the susceptibility to fipronil with resistance index varied from 0.97 to 2.64 in 2007 and 0.63 to 1.42 in 2008.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of BPH during 2004 and 2006. During 2004, BPH remained susceptible to phenyl-pyrazole group insecticides *viz.*, fipronil and ethiprole with RR values of 0.9 and 0.6, respectively. During 2006, BPH in Godavari delta continued to remain susceptible to phenyl pyrazoles like fipronil and ethiprole.

2.4.1.9 Insecticide Resistance in Rice Brown Planthopper, *N. lugens* (Stal) to other Groups of Insecticides

Fabellar *et al*. (1988) monitored the susceptibility of rice BPH collected from twelve Asian rice growing countries to different insecticides and reported that the BPH of Indonesia might be less susceptible to insecticides than BPH from India, Sri Lanka, Thailand and Japan.

Krishnaiah *et al*. (2002) studied the resistance development in *N. lugens* under greenhouse conditions by continuous exposing the insects to LC_{70} to LC_{80} concentrations of a recommended insecticide monocrotophos and the most effective neem formulation NG 4 once in each generation continuously for 26 generations. The results revealed that the NG 4 strain developed 1.98 to 2.15 times resistance to NG 4 and low cross resistance to cartap hydrochloride and imidacloprid. However, monocrotophos selected strain of *N. lugens* showed slight resistance to cartap hydrochloride.

Sujatha and Regupathy (2003) conducted dose response bioassays in BPH by using neem oil selected strain. The LD_{50} and LD_{90} values for neem oil did not vary much among the nine generations evaluated, indicating the absence of resistance to neem oil.

2.4.2 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath)

The WBPH, occurring in northern states like Haryana and Punjab alone has become a regular pest in several rice growing tracts in India (Krishnaiah *et al.*, 2004 and causes 35 to 90 per cent yield loss (Sidhu, 1979).

2.4.2.1 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Organo Chlorine Insecticides

Nagata and Kamimuro (2003) conducted experiments to know the insecticide resistance in migrating WBPH populations of China, Japan, Malaysia and Vietnam. Results obtained in the resistance monitoring trial conducted during 2000 revealed that Japan, Guilin and Malaysia populations gave almost similar values for the 10 insecticides tested, but LD_{50} value of the Malaysian population for DDT was 1/8 of the 1990 data. No significant difference was observed among the WBPH populations of three sites in China and those values coincided with the data of the Japan population.

2.4.2.2 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Organophosphorous Insecticides

Hosoda (1989) compared the topical LD_{50} values of seven field collected strains from different parts in Japan with the reference strain in the laboratory by topical application and observed 9 to 37 fold resistance to fentrothion, malathion, fenthion and phorate. Hirai (1994) reported widespread and high level of resistance in WBPH to malathion.

Xaofei *et al.* (2001) determined the insecticide susceptibility of WBPH collected from China and Japan in 1978 by topical application. The insecticide susceptibility of WBPH was not much different among the populations from Nagasaki (South West Japan), Hangzou (Zhejiang, China) and Jinghong (Yunnan, China). The LD_{50} values for WBPH were 96-130 mg/g for malathion and 100 mg/g for fenitrothion. The LD_{50} of monocrotophos was higher than other organophosphates.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of WBPH collected from Godavari delta during 2006. WBPH remained susceptible to acephate, monocrotophos recording RR values of around 1.0 or less than 1.0.

2.4.2.3 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Carbamate Insecticides

Hosoda (1989) compared the topical LD_{50} values of seven field collected strains from different parts in Japan with the reference strain in the laboratory by topical application and observed relatively low level of resistance (2 to 3 fold) to carbaryl and BPMC. Hirai (1994) reported relatively low level of resistance in WBPH to carbamates.

Xaofei *et al.* (2001) determined the insecticide susceptibility of WBPH collected from China and Japan in 1978 by topical application. The insecticide susceptibility of WBPH was not much different among the populations from Nagasaki (South West Japan), Hangzou (Zhejiang, China) and Jinghong (Yunnan, China). The LD_{50} for isoprocarb and propoxur for WBPH populations collected in 1997 were 5 times more than that of 1989.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of WBPH collected from Godavari delta during 2006. The WBPH exhibited low to moderate level of resistance to carbamate insecticide, BPMC (RR of 2.7).

2.4.2.4 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Non Ester Synthetic Pyrethroids

Xaofei *et al.* (2001) determined the insecticide susceptibility of WBPH collected from China and Japan in 1978 by topical application. The insecticide

susceptibility of WBPH was not much different among the populations from Nagasaki (South West Japan), Hangzou (Zhejiang, China) and Jinghong (Yunnan, China). The LD_{50} for WBPH was 0.047-0.062 mg/g for ethofenprox.

2.4.2.5 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Neonicotinoid Insecticides

Nagata *et al*. (2002) studied the insecticide resistance in long-range migrating WBPH by conducting trials in Japan, China (3 locations) and Malaysia. The LD_{50} values for the 2000 Japan BPH and WBPH coincided with those for the two China populations, but one of the China populations gave remarkably larger LD_{50} for imidacloprid.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field of populations of WBPH collected from Godavari delta during 2006 and reported that the WBPH exhibited resistance ratio of 2.7 for clothianidin but remained susceptible to thiamethoxam.

2.4.2.6 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Chitin Synthesis Inhibiting Insecticides

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of WBPH collected from Godavari delta during 2006 and reported that the WBPH exhibited low to moderate level of resistance to buprofezin (RR of 2.9).

2.4.2.7 Insecticide Resistance in Whitebacked Planthopper, *Sogatella furcifera* (Horvath) to Phenyl Pyrazole Insecticides

Matsumura *et al*. (2008) reported that insecticide resistance in WBPH against fipronil occurred widely in East and South East Asia.

Jhansilakshmi *et al*. (2010a) studied the levels of resistance in field populations of WBPH collected during 2006 from Godavari delta and reported that the WBPH remained susceptible to fipronil recording RR values of around 1.0 or less than 1.0. Jhansilakshmi *et al*. (2010b) reported that imidacloprid+ethiprole exhibited excellent initial and persistent toxicity against WBPH and GLH.

2.4.3. Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus Fallen*

The Smaller Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen (Homoptera: Delphacidae) is one of the most important insect pests infesting rice plants in Japan and transmitting the stripe virus. However, this hopper pest has not been reported from any part of Indian sub-continent including Bangladesh and Pakistan except for a stray observation at Punjab Agricultural University, Ludhiana during 1980. It is distributed from the Philippines to Siberia and Europe, mainly in the temperate zone (Esaki and Takeuchi, 1976 and Kisimoto, 1989).

2.4.3.1 Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen to Organophosphorous Insecticides

Kassai and Ozaki (1984) observed the changes in level of resistance to different groups of insecticides when a SBPH population with 370 fold resistance was selected with the synthetic pyrethroid, fenvalerate. The resistance to malathion was found decreased. Nagata and Ohiro (1986) observed 89 to 272 fold resistance to malathion in five populations collected from different regions of Japan.

Endo *et al*. (2002) from Ibaraki, Japan reported that the LD_{50} values of organophosphorous insecticides for the Northern Vietnam populations were almost the same as that for Fukuoka (Western Japan) population examined in 1967. The LD_{50} values of organophosphorous insecticides did not differ among the Zhejiang Province, China, Central Japan and South Western Japan populations.

Wang *et al*. (2010) reported that field populations of SBPH had developed medium to high resistance levels to organophosphate insecticides (e.g. chlorpyriphos and acephate) (RR was 10-12.6 folds and 9-13 folds, respectively) in China.

2.4.3.2 Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen to Carbamate Insecticides

Nagata and Ohiro (1986) observed 20 to 70 fold resistance to fenitrothion, diazinon, MTMC, carbaryl and MIPC In five populations collected from different regions of Japan.

Endo *et al*. (2002) from Ibaraki, Japan examined the insecticide susceptibility of *L.striatellus* collected from East Asia in 1992-94. The LD_{50} values of organophosphorous insecticides for the populations of Northern Vietnam and Yunan Province of China were lower than those of the populations of Zhejiang Province of China, Central Japan and South Western Japan. The LD_{50} values of carbamate insecticides for the Northern Vietnam populations were almost the same as that for Fukuoka (Western Japan) population examined in 1967. The LD_{50} values of carbamates for the KU population were the highest and those for Northern Vietnam populations were the lowest.

Wang *et al*. (2010) reported that field populations of SBPH had developed medium to high resistance levels to carbamate insecticides (e.g. carbaryl and propoxur) (RR was 29.8 - 45.3 folds and 40.1-131.5 folds, respectively) in China.

2.4.3.3 Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen to Synthetic Pyrethroid Insecticides

Kassai and Ozaki (1984) observed the changes in level of resistance to different groups of insecticides when a SBPH population with 370 fold resistance was selected with the synthetic pyrethroid, fenvalerate.

Endo *et al*. (2002) from Ibaraki, Japan examined the insecticide susceptibility of *L. striatellus* collected from East Asia in 1992-94. The LD_{50} values of ethofenprox, and fenvalerate showed no differences among all the populations tested. This showed that there was no cross resistance to synthetic pyrethroids (fenvalerate) in the carbamate resistant KU population of *L. striatellus*.

Wang *et al*. (2010) reported that field populations of SBPH had developed medium to high resistance levels to pyrethroid insecticides (e.g. cypermethrin and deltamethrin) (RR was 7.8 – 108.8 folds and 12-21 folds, respectively) in China.

2.4.3.4 Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen to Non Ester Synthetic Pyrethroids

Endo *et al*. (2002) from Ibaraki, Japan examined the insecticide susceptibility of *L. striatellus* collected from East Asia in 1992-94. The LD_{50} values of ethofenprox, showed no differences among all the populations tested. This showed that there was no cross resistance to ether derivatives (ethofenprox) in the carbamate resistant KU population of *L. striatellus*.

2.4.3.5 Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen to Neonicotinoid Insecticides

Wang *et al*. (2010) reported that field populations of SBPH had developed high levels of resistance to imidacloprid (RR was 44.6 to 108.8 folds) and no resistance to thiamethoxam (RR< 5 folds) in China.

2.4.3.6 Insecticide Resistance in Small Brown Planthopper (SBPH), *Laodelphax striatellus* Fallen to Chitin Synthesis Inhibitors

Wang *et al*. (2010) reported that field populations of SBPH had developed extremely high resistance levels to buprofezin (RR was over 200 folds) in China.

2.5 INFLUENCE OF SYNERGISTS ON INSECTICIDE RESISTANCE AND RESISTANCE MECHANISMS INVOLVED IN PLANTHOPPERS

The synergists increase the lethality and effectiveness of currently available insecticides but by themselves are considered nontoxic. The mode of action of the majority of synergists is to block the metabolic systems that would otherwise break down insecticide molecules. They interfere with the detoxification of insecticides through their action on poly-substrate monooxygenases (PSMOs) and other enzyme systems. The role of synergists in resistance management is directly related to an enzyme-inhibiting action, restoring the susceptibility of insects to the chemical, which would otherwise require higher levels of the toxicant for their control. In order to overcome the problem of resistance or to increase the effectiveness of insecticides, synergists are also used with organochlorines, organophosphates, carbamates, botanicals, pyrethroids etc.

Miyata *et al.* (1976) reported that one of the aliesterase isozymes of the malathion resistant strain decomposed malathion more than the susceptible strain.

Chung and Sun (1981a) reported that the synergist S, S, S-tri butyl phosphoro trithioate (DEF), an inhibitor of acetyl cholinesterase enhanced the toxicity of isoprocarb to the resistant strains of BPH.

Chung and Sun (1981b) investigated the effect of the esterase inhibitor S, S, S-tributyl phosphoro trithoate (DEF) on the toxicity of malathion, parathion methyl and parathion to 4th and 5th instar nymphs of a malathion-resistant strain of *N. lugens* in China. DEF enhanced the toxicity of malathion 20 times, that of parathion-methyl 6 times and that of parathion 11 times, implying that enzyme-mediated detoxification is associated with insecticide resistance in BPH.

Chung and Sun (1983) examined the possible contributions of hydrolytic and oxidative metabolism to malathion and isoprocarb (MIPC) resistance in BPH by using synergists TBPT and piperonyl butoxide. The role of microsomal oxidases was unclear in malathion resistance and was generally limited in isoprocarb resistance. Esterase hydrolysis was closely involved in malathion resistance and this was confirmed by spectrophotometry and electrophoresis.

Sun *et al.* (1984a) observed that BPH in Taiwan showed a high level of malathion resistance and various levels of resistance to isoprocarb and some other insecticides. Detoxification mediated by esterases, was associated closely with malathion resistance and, to a lesser extent, with resistance to several other organophosphorus compounds. Insensitive acetyl cholinesterase was primarily responsible for isoprocarb resistance, and it also contributed to the resistance to some other carbamates.

Sun and Dai (1984) found that, high esterase activity associated with OPs and carbamate resistance in *N. lugens* conferred a major part of the resistance to permethrin and other primary alcohol ester pyrethroids. Permethrin, phenothrin and fenpropathrin were synergized by piperonyl butoxide and DEF in the resistant strains, while only phenothrin was synergized in the susceptible strain. Cypermethrin was synergized only to a very limited extent, thus suggesting limited metabolism in these strains.

Kim and Hwang (1987) studied the biochemical difference between the resistant strains of BPH collected from Korea to organophosphorous insecticides and found that esterase activity in BPH treated with diazinon, fenitrothion or BPMC (fenobucarb) was not degraded in the resistant strain or in the F_1 hybrids but was markedly degraded in the susceptible strains.

Endo *et al*. (1988b) studied the development of insecticide resistance in rice brown planthopper and reported that malathion resistance in the malathion or MTMC-selected strains was suggested to be caused by high degradative activity of malathion and malaoxon. The mechanism of MTMC resistance in the MTMC-selected strain was presumed to be caused by low sensitivity of acetyl cholinesterase (AChe).

Wang *et al*. (1988b) showed that the frequency of individuals with high aliesterase (carboxyl esterase) activity increased gradually in each generation selected by carbofuran. In strains selected successively with carbaryl and malathion, carbofuran and malathion, carbaryl and monocrotophos and carbofuran and monocrotophos over 8 generations, the LC_{50} values were the same as that of the original susceptible strain.

Gu *et al*. (1993) studied the detoxifying enzymes of the brown planthopper. Among the major detoxifying enzymes, hydrolases were the most studied group because of their involvement in the resistance of BPH to both organophosphorus and pyrethroid insecticides. Activity of carboxylesterase toward 1-napthyl acetate in BPH was at least 20-fold higher than in some Lepidoptera.

Chen and Sun (1994) purified and characterized several of the BPH esterases isozymes from Japanese strains. They reported that the esterases had a dual role, hydrolyzing malathion and *trans*-permethrin and sequestering the oxon analogs of the OPs, the oxons acting as poor substrates for the esterases which bound them rapidly but then hydrolyzed them slowly.

Hemingway *et al*. (1999) studied two sibling species of *N. lugens* collected from cultivated rice and two from the grass *Leersia hexandra* and reported that the increased level of permethrin tolerance in the *Leersia* strain was synergized by the monooxygenase inhibitor piperonyl butoxide. This synergist had no effect on the toxicity of permethrin or propoxur to the Sri Lankan rice associated strain of *N. Lugens.*

Endo and Tsurumachi (2000) reported that insensitive AChE was one of the factors of carbamate and organophosphorous insecticide resistance in SBPH.

Graham and Hemingway (2000) reported that the resistant strain had higher activity and quantity of carboxyl esterase than the susceptible insects. The carboxyl esterases of *N. Lugens* being unable to hydrolyse parathion could bind strongly to the potent anti-choline esterase paraoxon and oxon of several organophosphate compounds.

John *et al*. (2001) studied the role of glutathione S-transferases in detoxification of pyrethroid resistant BPH. Selection of a laboratory colony of the BPH with the pyrethroids permethrin and lambda cyhalothrin increased its resistance to both insecticides. Biochemical analysis and synergistic studies with metabolic inhibitors indicated that elevated glutathione S-transferases (GSTs) with a predominant peroxidase activity conferred resistance to both pyrethroids, whereas esterases conferred part of the resistance to permethrin.

Endo *et al*. (2002) reported that the insensitivity of acetyl cholinesterase (AChE) for carbamate was one of the carbamate resistant factors in SBPH.

John *et al.* (2002) determined the nature of glutathione S-transferase involved in conferring pyrethroid resistance in BPH in UK.

Yoo *et al.* (2002) reported that the sensitivity of AChE to carbofuran or fenobucarb was reduced remarkably *in vitro* in the resistant strains while sensitivity to diazoxon changed only slightly. Insensitive AChE was considered to be the major resistance mechanism of the carbamate-resistant strains of the BPH.

Liu *et al.* (2002a) reported that triphenyl phosphate (TPP) significantly synergized methamidophos (SR 4.52) and moderately synergized malathion (SR 2.76), diazinon (SR 2.07), fenobucarb (SR 2.17) and isoprocarb (SR 1.64). Piperonyl butoxide (PBO) partially synergized methamidophos (SR 2.24), malathion (SR 1.86) and ethofenprox (SR 1.73).

Liu *et al.* (2003b) stated that TPP and diethyl maleate (DEM) had no synergistic effect on imidacloprid and PBO displayed significant synergism in some different strains, and the synergism increased with resistance (S strain 1.20, field population 1.43 and R strain 2.93). PBO synergism to cross-resistant insecticide was also found in the resistant strain (monosultap 1.25, acetamiprid 1.39, JS598 1.94 and JS599 2.02). The esterase and glutathione S-transferase played little role in imidacloprid detoxification. The increase of the P450-monooxygenase detoxification was an important mechanism for imidacloprid resistance and target resistance might also exist.

Liu *et al*. (2005) found that a nicotinic acetylcholine receptor (nAChR) mutation conferred target-site resistance to imidacloprid in BPH.

Wen *et al*. (2009) stated that the moderate to high level of resistance in Chinese BPH field population to imidacloprid might be due to the enhanced P450 monooxygenases detoxification.

Feng *et al*. (2010) reported that piperonyl butoxide and triphenyl phosphate exhibited significant synergism on thiamethoxam effects in the thiamethoxam-resistant strain (3.14 and 2.37 fold, respectively).

2.6 INSECTICIDE RESISTANCE MANAGEMENT WITH NEW INSECTICIDES

Management of resistant insect population with alternative and new insecticides is one of the tools in Insecticide Resistance Management (IRM) to reduce the selection pressure by continuous use of conventional insecticides.

The literature pertaining to the toxicity of new insecticides *viz.,* buprofezin. ethiprole, pymetrozine and imidacloprid + ethiprole (combination product) against BPH and other crop pests has been reviewed.

2.6.1 Resistance Management with Buprofezin

It is a chitin synthesis inhibitor (Benzyl phenyl urea) acting specifically on sucking insects and found harmless to the natural enemies, has low mammalian toxicity (Gerling and Sinai, 1994). It inhibits chitin synthetase enzyme and results in inability of insect to shed off the old cuticle and synthesize new cuticle.

Korat *et al.* (1999) reported lowest (2.72 to 3.73 hoppers/hill) number of WBPH in buprofezin 25 SC (0.5 kg a.i./ha) treated plots.

Bhavani and Rao (2005) reported that buprofezin 25 SC at 50 g a.i./ha and 100 g a.i./ha was effective in suppressing the population (82% and 85%) of planthoppers over control with 5067 and 5148 kg/ha yield in rice.

Kendappa *et al.* (2005) reported that buprofezin 25 SC @ 200 and 250 g a.i. /ha, imidacloprid 200 SL (Tatamida) @ 25 g a.i. /ha and thiamethoxam 25 WG @ 25 g a.i. /ha were significantly superior in suppressing of BPH up to 16 days after application.

2.6.2 Resistance Management with Ethiprole

Ethiprole is a newer chemical belonging to phenyl pyrazole group. The pyrazoles act on the Gamma Amino Butyric Acid (GABA) receptors of insects by blocking the passage of chloride ions, thereby causing disruption of the central nervous system (Cole *et al.,* 1993). The mode of action of pyrazoles is similar to cyclodienes and in general pyrazoles are highly specific to insects and are considered having low toxicity against mammals.

Ethiprole 10 SC @ 50 g. a.i. /ha and imidacloprid @ 25 g a.i. /ha were more effective than monocrotophos (500 g.a.i. /ha) against BPH and WBPH. (DRR, 2002). Varma *et al.* (2003) reported that ethiprole 10 SC @ 50 g a.i./ha was found effective against planthoppers compared to imidacloprid.

Sahithi and Misra (2006) observed that ethiprole 10 SC @ 50 g a.i./ha recorded significantly lowest population of green leafhoppers (GLH)/clump (0.8) with 89.7% reduction over control followed by alpha-cypermethrin @ 25 g a.i./ha (1.0 GLH/clump) at 15 days after spraying in rice.

Kumaran *et al.* (2007) stated that ethiprole 10 SC @ 50 g a.i./ha reduced 67.95 per cent of BPH population compared to untreated control.

Sekh *et al*. (2007) evaluated the efficacy of ethiprole 10% SC alone and in combination with imidacloprid 200 SL against BPH under field condition. The best result was obtained in ethiprole treated plots @ 37.5 and 50.0 g a.i./ha as well as in plots treated with the combination of ethiprole 10 SC and imidacloprid 20 SL @ either 25+25 or 25+37.5 g a.i./ha. The reduction of BPH population recorded in these plots was significantly superior in comparison to those observed in other treated plots.

2.6.3 Resistance Management with neonicotinoids and combinations

Single compound insecticides are generally not effective under diverse and complex pest situations. Therefore, combination products having two or more molecules belonging to diverse groups of insecticides can be used to manage different pests.

Krishnaiah *et al*. (2003) reported that thiamethoxam and imidacloprid showed high degree of efficacy even at 25 g a.i. /ha against brown planthopper.

Krishnaiah *et al*. (2004) stated that the phenyl pyrazole insecticides *viz.*, fipronil and ethiprole (50 ppm each) were slower in their action against BPH and WBPH and showed poor initial and persistent toxicity against GLH.

Imidacloprid was the best insecticide comparable to acephate against rice planthoppers (Bhavani and Rao, 2005).

Imidacloprid @ 0.25 ml/l effectively reduced the BPH and WBPH populations in rice (76.05% and 78.93%, respectively) (Seetharamu *et al.*, 2005)

Ethiprole 40% + imidacloprid 40% @ 100 g a.i./ha, thiamethoxam 12.6%+lambda cyhalothrin Zeon 9.4% (Alika 247 ZC) @ 44 g a.i./ha were superior to the monocrotophos @ 500 g a.i./ha in controlling planthoppers (DRR, 2006 and 2007).

Ethiprole 40 % + Imidacloprid 40 % - 80 WG @ 125 g ha^{-1} recorded more than 90 per cent reduction in the population of leafhopper and planthopper in rice (Vinothkumar *et al*., 2010)

2.6.4 Resistance Management with Pymetrozine

It is a pyridine azomethine compound found to inhibit the feeding of sucking insects.

Pymetrozine 50 WG @ 150 g.a.i./ha was reported effective against planthoppers (DRR, 2008). Pymetrozine 50 WG @ 400, 350, 300, 250 and 200 g ha^{-1} was superior in minimizing the population of brown planthopper in rice (Muralibaskaran *et al*., 2009). Due to its phloem mobility it was found effective against plant sucking insects (Wyss and Balsinger, 1997).

Other Pests

Slosser *et al*. (2000) stated that the pymetrozine reduces the cotton aphids more effectively. Polston and Sherwood (2003) reported that pymetrozine provided protection against tomato yellow leaf curl virus by viruliferous white flies *Bemisia tabaci* (Gennadius).

2.7. EFFECT OF INSECTICIDE RESISTANCE ON BIOLOGY OF INSECT PESTS

Liu *et al*. (2003a) reported that that resistant strains of BPH had developmental disadvantages, including a lower nymphal survival rate from neonate to 2nd instars, a lower adult emergence rate and shorter female life-span, as well as reproductive disadvantages such as lower copulation rate, effective fecundity and hatchability. In addition, the resistant strain had prolonged egg duration and a lower nymphal survival rate from the 3rd to 5th instars.

Roan and Hopkins (1961) suggested that insecticides positively stimulate neural activity to bring about a favourable neurohormonal influence on insect reproduction.

Parry and Ford (1972) reported that phosphamidon exerted positive effect on population build up of green peach aphid, *M. persicae* by increasing its fecundity and longevity. Eggers-Schumacher (1983) stated that strains resistant to organophosphorus insecticides had shorter developmental times and reproduced faster than susceptible strains of green peach aphid. Coombes (1983) did not observe any effect on *M. persicae* when exposed to a sub-lethal dose of demeton-s-methyl but the fecundity of F_1 progenies of the aphid increased from 12.0 to 14.0 nymphs per aphid per 4 days.

Singh (1992) observed that sub-lethal concentration of endosulfan produced significant increase in the fecundity of *L. erysimi*. Pasupathy and Regupathy (1992) reported that the population of *A. gossypii* depended on the number of applications of deltamethrin, cypermethrin and fenvalerate rather than the dose.

Chlorpyriphos significantly enhanced the fecundity of *L. erysimi* by prolonging the reproductive period (Sarao, 1996). There was no significant difference in vitality and reproductivity between monocrotophos resistant populations and susceptible *Bemisia tabaci* (Feng *et al.*, 1996).

Hollingsworth *et al.* (1997) measured fecundity across 15 populations of *A. gossypii* and showed that the relationship between the logarithm of the LC_{50} and mean daily progeny production in the absence of insecticide exposure was negative for esfenvalerate, positive for methomyl and not significant for endosulfan and oxydemeton methyl.

Sohi *et al.* (1998) reported that repeated sprays of fenvalerate, monocrotophos and endosulfan increased reproduction of cotton aphid by 16.42, 50.23 and 68.52 per cent, respectively, as compared with untreated check. Repeated applications of carbaryl reduced fecundity by 35.36 per cent. Rider and Wilde (1998) suggested that insecticide resistance was associated with reduced fecundity in insecticide resistant clones of *S. graminum*.

Chapter III

MATERIAL AND METHODS

The present "Studies on assessment and management of insecticide resistance in Rice brown planthopper, *Nilaparvata lugens* (Stal)" were carried out under laboratory conditions at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district, Andhra Pradesh during 2008-2009 and 2009-2010. The materials used and the methods employed during the course of present investigations are presented in this chapter.

3.1 COLLECTION OF *Nilaparvata lugens* (Stal)

Field populations of *Nilaparvata lugens* (Stal) were collected on rice crop from farmers' fields of East Godavari, West Godavari and Karimnagar districts of Andhra Pradesh and reared in polyhouse for subsequent generations and tested for phenotypic expression of susceptibility and for various other studies (Plates 1 & 2).

3.1.1 Mass Rearing of *N. lugens* (Stal)

The populations of BPH were reared for 3-4 generations on susceptible rice variety TN1 before testing with insecticide to ensure uniform and steady supply of insects. The rearing cages of size 65 x 75 x 95 cm having glass panes with a small window on the side and fine wire mesh on three sides were used for rearing the BPH. The pots with a susceptible rice variety TN1 were kept inside the cages and gravid females were released to multiply their progenies (Plate 3). Likewise, the BPH populations from each of the three locations were multiplied separately in rearing cages on TN1 rice plants.

3.1.2 Mass Rearing of Susceptible Strain of BPH

The population of BPH which was not exposed to any insecticide and continuously maintained on susceptible rice cultivars at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru was taken as susceptible population for the present studies.

3.2 EVALUATION OF DEGREE OF RESISTANCE ACQUIRED BY *N. lugens* TO COMMONLY USED INSECTICIDES

3.2.1 Test Insecticides

The technical grade insecticides of endosulfan, monocrotophos, phosphamidon, acephate, fenobucarb, ethofenprox, imidacloprid, and thiamethoxam representing five different groups of conventional usage *viz*., cyclodiene, organophosphate, carbamate, synthetic pyrethroid and neonicotinoids were used for bioassay studies to assess the degree of resistance acquired by *N. lugens* (Table 3.1 & Plate 4a).

3.2.2 Preparation of Stock Solution

Initially a 1.0 per cent stock solution was prepared by dissolving the required quantities of technical grade insecticides in acetone. Triton X-100 (1.0%) was used as emulsifier. One hundred ml stock solution thus prepared was preserved in refrigerator for further use as and when required. Further dilutions were made from the 1.0 per cent stock solution after it attained the room temperature.

3.2.3 Preparation of Test Concentrations of Insecticidal Emulsions

The individual working concentrations for each of the test insecticides were prepared from the 1.0 per cent solution through serial dilution technique using distilled water as solvent (Gouse, 2005).

3.2.4 Bioassay

To assess the relative toxicity of insecticides to BPH populations of different locations, the insecticides were sprayed on 40 days old susceptible rice cultivars in serial concentrations. Immediately after drying of the spray deposit, 7-9 day old nymphs of the BPH (20 nos.) were released with aspirator and confined with the help of mylar cages. A control test was also carried out with distilled water alone on the nymphs of BPH and mortality was assessed (Krishnaiah *et al*., 2002 and Krishnaiah *et al*., 2004) (Plates 4b & 4c).

3.2.5 Data Collection

The data on mortality were recorded at 24, 48 and 72 hours after spray. The pooled mortality at 72 hours after spray was subjected to statistical analysis.

The test insects that fell on their back and unable to recover normal posture were counted as dead. The moribund nymphs also were considered as dead while recording the mortality data.

The treatment mortality data were corrected using Abbott's formula (Abbott, 1925) when ever mortality was recorded in control. Initially wider range concentrations of insecticides solutions and subsequently narrower range were tested. The data of each test insecticide in the range of 5 to 90 per cent mortality were subjected to probit analysis (Finney, 1971) using the MLP software (Ross, 1987) for obtaining LC_{50}, LC_{90}, heterogeneity (χ^2), intercept (a), slope of regression line (b), fiducial limits and log concentration probit lines (lcp). The same procedure was adopted for each of the test insecticides against the BPH populations from the three districts *viz.*, East Godavari, West Godavari and Karimnagar and susceptible population.

3.2.6 Assessment of the Degree of Resistance Acquired by *N. lugens* to Selected Insecticides.

The relative degree of resistance acquired by different populations was assessed adopting standard formula (FAO, 1979).

$$\text{Resistance Factor} = \frac{LC_{50}/LC_{90} \text{ of resistant population}}{LC_{50}/LC_{90} \text{ of susceptible population}}$$

The degree of resistance acquired by the different populations of *N. lugens* was calculated by comparing the LC_{50} and LC_{90} values obtained in the present study with the corresponding values of the susceptible population, baseline data and field recommended concentrations.

Graphical presentations of log concentration probit lines (lcp) for all the insecticides of the present studies were done.

3.3. STUDIES ON INFLUENCE OF SYNERGISTS ON INSECTICIDE RESISTANCE

Piperonyl Butoxide and Triphenyl Phosphate were used to test the role of mixed function oxidases and esterases in the acquisition of resistance acquired by BPH. The synergists were mixed with each of the following insecticides *viz.*, endosulfan,

monocrotophos, phosphamidon, acephate, fenobucarb, ethofenprox, imidacloprid, and thiamethoxam in 1:10 ratio and used on relatively resistant population of *N. lugens* to test the synergistic effect. The details of synergists used are given in table 3.2.

3.3.1 Preparation of Mixtures of Insecticides and Synergists in the Ratio of 1:10.

The synergists were diluted to 1.0 per cent stock solution using acetone as diluents. It was further diluted to the desired concentrations by serial dilution technique. Desired concentrations of insecticidal emulsions were prepared. The insecticide and the synergists were mixed at two and twenty fold higher than the desired concentration of the test insecticide in the ratio of 1:1 by volume to maintain the concentration of insecticide and synergist in 1:10 ratio in the mixture (Chalam, 2000).

3.3.2 Bio-assay of Test insecticide and Synergist Mixture against *N. lugens*

The toxicity of insecticide synergist mixture of different concentrations was tested against BPH for each of the eight test insecticides at 1:10 ratio and the mortality of BPH was recorded. Control mortality was also assessed. Mortality data were corrected by Abott's formula and the LC_{50} and LC_{90} values were calculated following probit analysis (Finney, 1971).

3.3.3 Computation of Synergistic Factor

The extent of synergism obtained due to the mixing of synergists with the test insecticides was assessed by comparing the LC_{50} value of insecticide alone with the LC_{50} value of the mixture of insecticide and synergist and the synergistic factor was calculated. The same procedure was followed in case of LC_{90} also and the extent of synergism was determined at 1:10 ratio of the insecticide and synergist (Chalam, 2000).

Synergistic factors (LC_{50}/LC_{90} of the insecticide alone divided by LC_{50}/LC_{90} of insecticide + Synergist) indicate any possible bio-activation of insecticide or detoxification of insecticide by monooxygenases which could help to explain the possible mechanism (Metcalf, 1967).

$$\text{Synergistic factor} = \frac{LC_{50}/LC_{90} \text{ of the insecticide alone}}{LC_{50}/LC_{90} \text{ of the insecticide + Synergist}}$$

If the synergistic ratio is <1 - Antagonistic effect

>1 - Synergistic effect

= 1 - Additive effect

3.4 MANAGEMENT OF INSECTICIDE RESISTANCE IN *N. lugens* WITH NEW INSECTICIDES HAVING NOVEL MODE OF ACTION

The *N. lugens* population of West Godavari district which was found relatively more resistant than the other populations was selected for this study. The selected new insecticides *viz.*, buprofezin 25 SC, ethiprole 10 SC, pymetrozine 50 WG and imidacloprid + ethiprole (40+40) 80 WG (combination product) were included for the management of insecticide resistance in this study. The particulars of these insecticides are furnished in the Table 3.3.

The test insecticides were dissolved in water to have different working concentrations. The insecticides were sprayed on 40 days old susceptible rice cultivars in serial concentrations. Immediately after drying of the spray deposit, 7-9 day old nymphs of the BPH (20 nos.) were released with aspirator and confined with the help of mylar cages. A control was also maintained with water as one of the treatments. Post treatment mortality was recorded at 24, 48 and 72 hours after spray and the pooled mortality at 72 hours after spray was subjected to statistical analysis. For slow acting compounds such as buprofezin, the mortality data was recorded after 5 days.

The corrected mortality data was analyzed through MLP software (Ross, 1987) and LC_{50}, LC_{90}, heterogeneity (χ^2), intercept (a), slope of regression line (b), fiducial limits and log concentration probit lines (lcp) were obtained.

The relative toxicity of these insecticides was calculated by dividing the LC_{50} and LC_{90} values of each of the conventional insecticides *viz.*, endosulfan, monocrotophos, phosphamidon, acephate, fenobucarb, ethofenprox, imidacloprid, and thiamethoxam with the corresponding values of each of the new insecticides tested and thus the preference of the new insecticides over the conventional one was determined for the management of resistant West Godavari BPH population.

$$\text{Toxicity Index/Relative toxicity} = \frac{LC_{50}/LC_{90} \text{ of the conventional insecticide}}{LC_{50}/LC_{90} \text{ of the new insecticide}}$$

3.5 EFFECT OF INSECTICIDE RESISTANCE ON THE BIOLOGY OF *N. lugens*

The biology of susceptible, East Godavari, West Godavari and Karimnagar populations of BPH was studied by recording egg period, the duration of nymphal instars, total nymphal period, longevity of adults, pre oviposition period, oviposition period and number of progenies to know the effect of insecticide resistance. Each observation was made for 25 BPH which constituted as five replications (Plates 5a & 5b).

3.5.1 Egg Period

To study the egg period, one gravid female (4-5 days) of BPH from different populations was confined for a day on rice plant (40-50 days old) and the emergence of nymphs was observed (Krishnaiah *et al.*, 2005).

3.5.2 Number of Progeny

To study the total progeny produced by one female, one pair of male and female adults of BPH (0-day old) were released on rice plants (40-50 days old) covered with mylar film. These BPH were observed daily for the progeny laid. The total number of young nymphs born per day was recorded. These nymphs were removed daily and the total progeny was recorded for the entire period.

3.5.3 Duration of Nymphal Instars

To study the number and duration of nymphal instars, just hatched BPH nymphs (25 No.s) were released into the test tubes (10 cm depth) containing rice stem bits. The stem bits were replaced daily with fresh ones.

The number and duration of moults were recorded till the nymphs became adults. The nymphal period of individual instars and total nymphal period was recorded and mean was calculated (Krishnaiah *et al*., 2005).

3.5.4 Measurement of Pre Oviposition and Oviposition Periods

Twenty five adults within 24 hours after eclosion (0-day adult) were paired in a glass test tube (10 cm depth) with one or two rice seedlings. The rice seedlings were checked daily under a binocular microscope for the presence of eggs. The rice seedlings were changed every day and checked for eggs on them (Wada *et al*., 2007).

3.5.5 Longevity of Adults

The period between the date of 5th moult and mortality was considered as the longevity of adult BPH. Adult life span for brachypterous females and macropterous males were computed separately (Krishnaiah *et al*., 2005). The period from the date of birth to the date of death was considered as the total life cycle or longevity of BPH (Jhansi, 2003).

3.5.6 Statistical Analysis

The parameters *viz.*, egg period, the duration of nymphal instars, longevity of adults, pre oviposition period, oviposition period, and number of progeny were subjected to statistical analysis using simple Completely Randomized Design (CRD) ((Duncan, 1955).

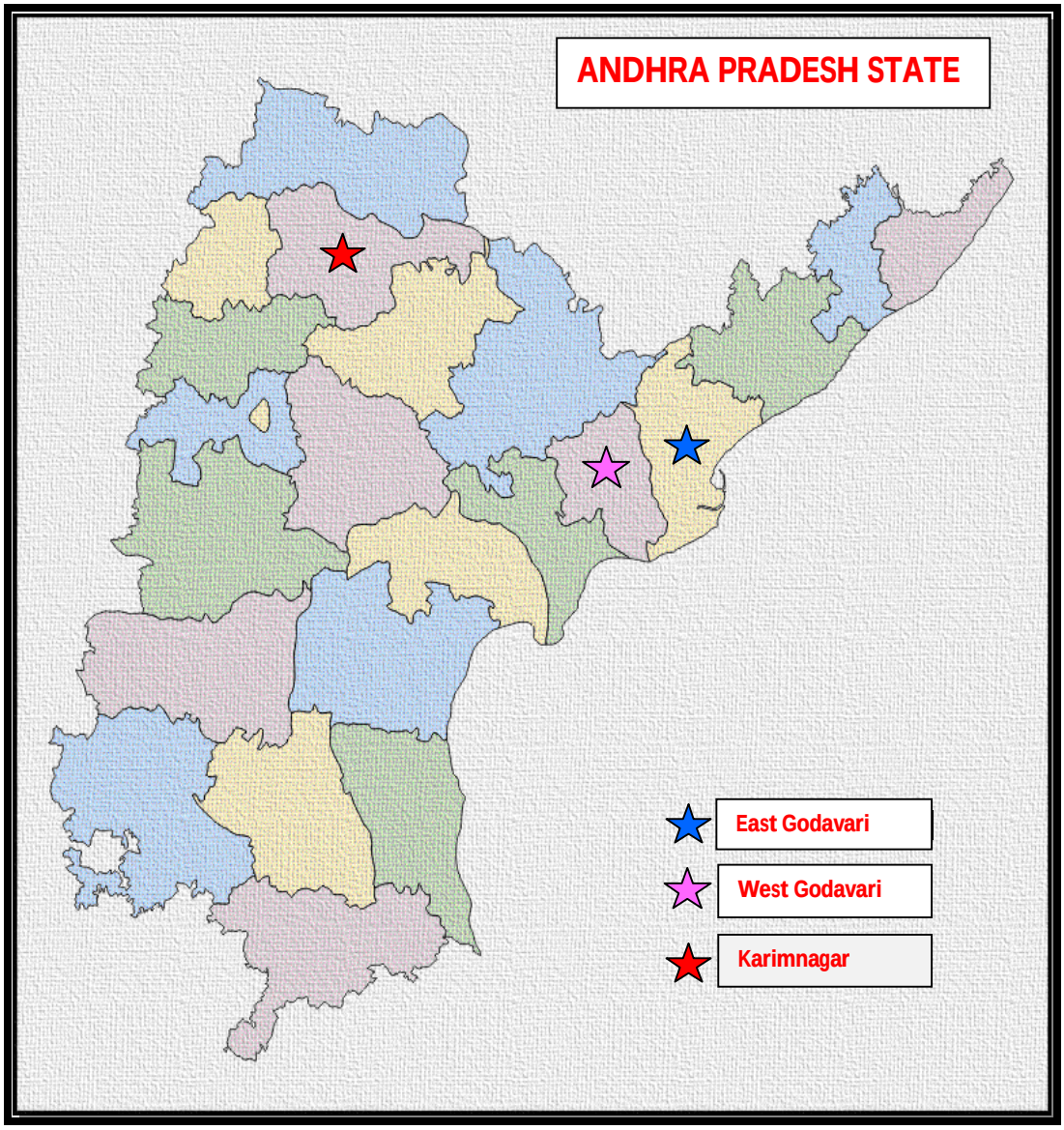
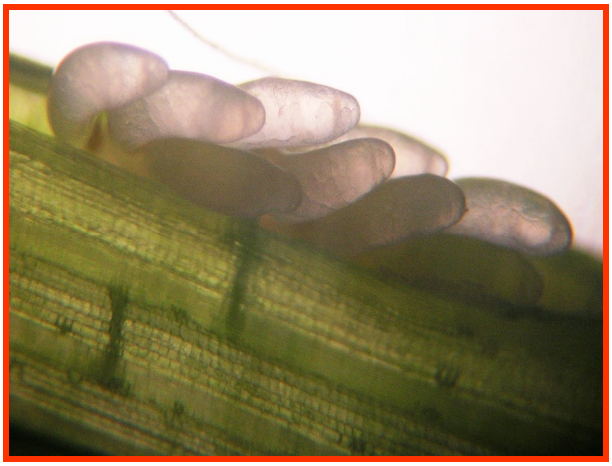


Plate 1. Map showing the districts selected to assess the Insecticide Resistance.



2 a. Eggs



2 b. Adult female



2 c. Adults and nymphs

Plate 2. External features of *Nilaparvata lugens* (Stal)



3 a. Rearing cages



3 b. Rearing cage: Open

Plate 3. Mass rearing of *Nilaparvata lugens* (Stal)



4 a. Insecticides used



4 b. Apparatus used



4 c. Bio-assay

Plate 4. Bio-assay of *Nilaparvata lugens* (Stal)



5 a. Studies on number of progeny



5 b. Studies on Nymphal instars and duration

Plate 5. Biology studies of *Nilaparvata lugens* (Stal)

CHAPTER IV

RESULTS AND DISCUSSION

The "Studies on assessment and management of insecticide resistance in rice brown planthopper, *Nilaparvata lugens* (Stal)" were carried out under laboratory conditions at Andhra Pradesh Rice Research Institute (APRRI) and Regional Agricultural Research Station (RARS), Maruteru, West Godavari district, Andhra Pradesh during 2008-2009 and 2009-2010. The results of the present investigations are presented and discussed here under.

4.1 TOXICITY OF SELECTED INSECTICIDES TO *N. lugens* OF DIFFERENT LOCATIONS

4.1.1 Endosulfan

4.1.1.1 Susceptible population

The LC_{50} and LC_{90} values of endosulfan against susceptible population of BPH were 0.0097 and 0.0404 per cent and 0.0107 and 0.0443 percent during 2008-09 and 2009-10, respectively (Table 4.1). The 'b' value of log concentration probit (lcp) line was 2.0761 (Fig. 4.1).

The chi-square test indicated that the BPH population used in this investigation was homogenous during both 2008-09 and 2009-10. The slope (b) value of lcp line of endosulfan was 2.0864 (Fig. 4.2).

4.1.1.2 East Godavari population

During 2008-09, the data showed that the LC_{50} and LC_{90} values of endosulfan against BPH population of East Godavari were 0.0343 and 0.1162 per cent, respectively (Table 4.1). The chi-square test indicated the BPH population used in this investigation was homogenous. The slope of the log concentration probit (lcp) line (b) was 2.4203 (Fig. 4.1).

During 2009-10, the LC_{50} and LC_{90} values of endosulfan against BPH population of East Godavari were 0.0324 and 0.1179 per cent, respectively (Table 4.1). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope (b) value of lcp line of endosulfan was 2.2854 (Fig. 4.2).

4.1.1.3 West Godavari population

During 2008-09, West Godavari population of BPH recorded the LC_{50} and LC_{90} values 0.0353 and 0.1053 per cent, respectively (Table 4.1). The chi-square test revealed that the BPH population used in this study was homogenous. The slope (b) value of lcp line was 2.6988 (Fig. 4.1).

During 2009-10, the BPH of West Godavari district has recorded the LC_{50} and LC_{90} values 0.0339 and 0.1120 per cent, respectively (Table 4.1). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 2.4717 (Fig. 4.2).

4.1.1.4 Karimnagar population

During 2008-09, the data showed that the LC_{50} and LC_{90} values of endosulfan against BPH population of Karimnagar districts were 0.0205 and 0.0508 per cent, respectively (Table 4.1). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope of the log concentration probit (lcp) line (b) was 3.2497 (Fig. 4.1).

During 2009-10, the LC_{50} and LC_{90} values of endosulfan against BPH population of Karimnagar district were 0.0214 and 0.0555 per cent, respectively (Table 4.1). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope (b) value of lcp line of endosulfan was 3.1090 (Fig. 4.2).

The variations in the LC_{50} values in the three districts represent different selection pressure and consequent resistance to endosulfan.

The LC_{50} and LC_{90} values against BPH populations of West Godavari and East Godavari districts were higher than that of Karimnagar population. The large contiguous areas of rice cultivation in these two districts and high insecticidal use might have contributed to higher LC_{50} and LC_{90} values. These results are in agreement with Armes *et al*. (1992) who reported that a high level of resistance was quite common in crops that have been regularly sprayed with insecticides.

4.1.2 Monocrotophos

4.1.2.1 Susceptible population

During 2008-09 the LC_{50} and LC_{90} values of monocrotophos against susceptible population of BPH were 0.0230 and 0.0915 per cent, respectively (Table 4.2). Population was homogeneous as indicated by the chi-square test. The log concentration probit line recorded a slope (b) of 2.1425 (Fig 4.3).

During 2009-10, the LC_{50} and LC_{90} values of monocrotophos against susceptible population of BPH were 0.0216 and 0.0797 per cent, respectively (Table 4.2). Population was homogeneous as indicated by the chi-square test. The log concentration probit line recorded a slope (b) of 2.2628 (Fig 4.4).

4.1.2.2 East Godavari population

During 2008-09, East Godavari strain of BPH recorded the LC_{50} and LC_{90} values of 0.0545 and 0.0985 per cent, respectively (Table 4.2). Population was homogeneous as indicated by the chi-square test. The slope (b) value of lcp line of monocrotophos was 4.9827 (Fig. 4.3).

During 2009-10, East Godavari strain of BPH recorded the LC_{50} and LC_{90} values of 0.0539 and 0.1047 per cent, respectively (Table 4.2). Population was homogeneous as indicated by the chi-square test. The slope (b) value of lcp line of monocrotophos was 4.4424 (Fig. 4.4).

4.1.2.3 West Godavari population

During 2008-09, the data indicated that LC_{50} and LC_{90} values of monocrotophos to the west Godavari population of BPH were 0.0694 and 0.1201 per cent, respectively (Table 4.2). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope of lcp line (b) was 5.3805 (Fig 4.3).

During 2009-10, the LC_{50} and LC_{90} values of monocrotophos to the west Godavari population of BPH were 0.0654 and 0.1190, respectively (Table 4.2). Population was homogeneous as indicated by the chi-square test. The log concentration probit line recorded a slope (b) of 4.9361 (Fig 4.4).

4.1.2.4 Karimnagar Population

During 2008-09, the data showed that the LC_{50} and LC_{90} values of monocrotophos against BPH population of Karimnagar district were 0.0540 and 0.0992 per cent, respectively (Table 4.2).The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope of the lcp line (b) was 4.8515 (Fig. 4.3).

During 2009-10, the LC_{50} and LC_{90} values of monocrotophos against BPH population of Karimnagar district were 0.0544 and 0.1047 per cent, respectively (Table 4.2). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope of the lcp line (b) was 4.5119 (Fig. 4.4).

The LC_{50} values of the three populations in the present studies were higher than the LC_{50} values of monocrotophos against *N. lugens.* This is in agreement with the earlier reports of Sarupa *et al.* (1998) (0.0172%); Krishnaiah *et al.* (2002) (0.0043%); Jhansilakshmi *et al*. (2010a) (0.0135% for East Godavari strain & 0.0146% for West Godavari strain) and is a clear indication of the resistance acquisition.

4.1.3 Acephate

4.1.3.1 Susceptible population

During 2008-09, the LC_{50} and LC_{90} values of acephate against susceptible population of BPH were 0.0228 and 0.1069 per cent, respectively (Table 4.3). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope (b) value of lcp line was 1.9141 (Fig. 4.5).

During 2009-10, the LC_{50} and LC_{90} values of acephate against susceptible population of BPH were 0.0237 and 0.0980 per cent, respectively (Table 4.3). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope (b) value of lcp line of acephate was 2.0816 (Fig. 4.6).

4.1.3.2 East Godavari population

During 2008-09, the LC_{50} and LC_{90} values of acephate against East Godavari population of BPH were 0.0554 and 0.1060 per cent, respectively (Table 4.3). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope (b) value of lcp line was 4.5529 (Fig. 4.5).

During 2009-10, the LC_{50} and LC_{90} values of acephate against East Godavari population of BPH were 0.0560 and 0.1165 per cent, respectively (Table 4.3). The chi-square test indicated that the BPH population used in this investigation was homogenous. The slope (b) value of lcp line of acephate was 4.0277 (Fig. 4.6).

4.1.3.3 West Godavari population

During 2008-09, the LC_{50} and LC_{90} values of acephate (Table 4.3) against the BPH population of West Godavari district were 0.0640 and 0.1184 per cent, respectively. The slope (b) of the lcp line was 4.8033 (Fig 4.5) and the BPH population used for the study was homogeneous.

During 2009-10, the LC_{50} and LC_{90} values of acephate (Table 4.3) against BPH population of West Godavari district were 0.0662 and 0.1256 per cent, respectively. The slope (b) of the lcp line was 4.6164 (Fig. 4.6) and the BPH population used for the study was homogeneous.

4.1.3.4 Karimnagar population

During 2008-09, it is clear from the table 4.3. that the LC_{50} and LC_{90} values of acephate against BPH population of West Godavari district were 0.0415 and 0.0951 per cent, respectively. The slope (b) of the lcp line was 3.5598 (Fig. 4.5) and the BPH population used for the study was homogeneous.

During 2009-10, the LC_{50} and LC_{90} values of acephate (Table 4.3) against BPH population of West Godavari district were 0.0505 and 0.0980 per cent, respectively. The slope (b) of the lcp line was 4.4604 (Fig. 4.6) and the BPH population used for the study was homogeneous.

The LC_{50} values of three populations of East Godavari (0.054%-0.0560%), West Godavari (0.0640%-0.0662%) and Karimnagar (0.0415%-0.0505%) were slightly higher than the susceptible population. But, the LC_{50} values of the three populations in the present studies were higher than the LC_{50} value of acephate against *N. lugens* reported by Jhansilakshmi *et al*. (2010a) (0.0056% for East Godavari strain and 0.0053% for West Godavari strain). That is a clear indication of the resistance acquisition.

The results of acephate are in conformity with the studies of Kumaran *et al.* (2007)., Sekh *et al.* (2007) and Shashank (2009) who reported that acephate (0.12%) was moderately effective against BPH under field conditions.

The variability in efficacy might be attributed to differences in the susceptibility of the pest at different places as well as in the concentration of insecticide used.

4.1.4 Phosphamidon

4.1.4.1. Susceptible population

During 2008-09, the data (Table 4.4) showed that the LC_{50} and LC_{90} values of phosphamidon to the susceptible population of BPH were 0.0331 and 0.0784 per cent, respectively. The chi-square test revealed that the homogeneity of the BPH population used in the study. The slope (b) value was 3.4246 (Fig. 4.7).

During 2009-10, the data (Table 4.4) showed that the LC_{50} and LC_{90} values of phosphamidon to the susceptible population of BPH were 0.0313 and 0.1009 per cent, respectively. The chi-square test revealed that the homogeneity of the BPH population used in the study. The slope (b) value was 2.5445 (Fig. 4.8).

4.1.4.2. East Godavari population

During 2008-09, East Godavari strain of BPH recorded the LC_{50} and LC_{90} values of 0.0657 and 0.1057 per cent, respectively (Table 4.4).

Population was homogeneous as indicated by the chi-square test. The slope (b) value of lcp line of phosphamidon was 6.2183 (Fig. 4.7).

During 2009-10, East Godavari strain of BPH recorded the LC_{50} and LC_{90} values of 0.0639 and 0.1103 per cent, respectively (Table 4.4). Population was homogeneous as indicated by the chi-square test. The slope (b) value of lcp line of phosphamidon was 5.4034 (Fig. 4.8).

4.1.4.3 West Godavari Population

During 2008-09, the LC_{50} and LC_{90} values of phosphamidon (Table 4.4) against BPH population of West Godavari district were 0.0734 and 0.1095 per cent, respectively. The slope (b) of the lcp line was 7.3795 (Fig. 4.7) and the BPH population used for the study was homogeneous.

During 2009-10, the LC_{50} and LC_{90} values of phosphamidon (Table 4.4) against BPH population of West Godavari district were 0.0722 and 0.1121 per cent, respectively. The slope of the lcp line was 6.7125 (Fig. 4.8) and the BPH population used for the study was homogeneous.

4.1.4.4 Karimnagar Population

During 2008-09, the LC_{50} and LC_{90} values of phosphamidon against BPH population of Karimnagar district were 0.0641 and 0.1184 per cent, respectively (Table 4.4). The slope (b) of the lcp line was 4.8033 (Fig.4.7). The population of BPH used for the study was homogeneous.

During 2009-10, the LC_{50} and LC_{90} values of phosphamidon against BPH population of Karimnagar district were 0.0665 and 0.1227 per cent, respectively (Table 4.4). The slope (b) of the lcp line was 4.7066 (Fig. 4.8). The population of BPH used for the study was homogeneous.

The results of the experiment revealed that the LC_{50} values obtained in the present study were higher (0.0043%) than that recorded by Sarupa *et al.* (1998) against *N. lugens* of Godavari strain which may probably be due to variation in the test insect and also due to the acquisition of resistance by *N. lugens.* The LC_{90} values of the three test populations of the present study were slightly higher than LC_{90} values of susceptible population (0.0784 %) which may probably due to acquisition of moderate degree of resistance by certain proportion of BPH populations in these three districts.

The differences in the LC_{50} and LC_{90} values of phosphamidon among the three BPH populations might be due to geographical variations of the areas from which test insects were collected similar to the findings of Kerns and Gaylor (1992) in cotton aphid and also due to variable pesticide consumption rates in different districts and the consequent selection pressure. Sujatha and Regupathy (2003) also found variability in resistance ratios (2.2, 1.7 and 1.3) for phosphamidon selected strain of BPH at LD_{50}, LD_{90} and LD_{99}, respectively.

4.1.5 Fenobucarb

4.1.5.1 Susceptible population

During 2008-09, it is clear from the data (Table 4.5) that susceptible population of BPH has LC_{50} and LC_{90} values of 0.0054 and 0.0109 per cent, respectively to fenobucarb. The slope of (b) of the lcp line was 4.2859 (Fig. 4.9) with non-significance of chi-square test indicating that the BPH population tested was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of fenobucarb against susceptible BPH population were 0.0052 and 0.0105 per cent, respectively (Table 4.5). The slope of (b) of the lcp line was 4.2077 (Fig. 4.10) with non-significance of chi-square test indicating that the BPH population tested was homogenous.

4.1.5.2 East Godavari Population

During 2008-09, the LC_{50} and LC_{90} values of fenobucarb to the East Godavari population of BPH were 0.0076 and 0.0122 per cent, respectively (Table 4.5). The slope (b) value of lcp line of fenobucarb was 6.3690 (Fig. 4.9). The chi-square test revealed that the population used in the study was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of fenobucarb to the East Godavari population of BPH were 0.0075 and 0.0132 per cent, respectively (Table 4.5). The slope (b) value of lcp line of fenobucarb was 5.2335 (Fig. 4.10). The chi-square test revealed that the population used in the study was homogenous.

4.1.5.3 West Godavari Population

During 2008-09, BPH population of West Godavari population has recorded the LC_{50} and LC_{90} values 0.0075 and 0.0115 percent, respectively (Table 4.5). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 6.8764 (Fig. 4.9).

During 2009-10, the BPH population of West Godavari district has recorded the LC_{50} and LC_{90} values 0.0088 and 0.0158 per cent, respectively (Table 4.5). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 5.0434 (Fig. 4.10).

4.1.5.4 Karimnagar Population

During 2008-09, Karimnagar population of BPH has recorded the LC_{50} and LC_{90} values 0.0069 and 0.0116 per cent, respectively (Table 4.5). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 5.3120 (Fig. 4.9).

During 2009-10, the BPH population of Karimnagar district has recorded the LC_{50} and LC_{90} values 0.0069 and 0.0136 per cent, respectively (Table 4.5). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 4.3780 (Fig. 4.10).

The LC_{50} values of these three test populations of the present study were slightly higher than the susceptible population and slightly lower than the LC_{50} value of fenobucarb against West Godavari strain of *N. lugens* (0.0168%) as reported by Sarupa *et al.* (1998). Krishnaiah *et al.* (2002) reported that the LC_{50} values of fenobucarb for monocrotophos selected and laboratory reared strains of BPH were 0.001051% (10.51 ppm) and 0.0009% (9.003 ppm), respectively.

The LC_{50} value of the East Godavari strain of the present study was almost similar to the values reported by Jhansilakshmi *et al*. (2010a) (0.0081%) and the LC_{50} value of West Godavari strain was slightly higher than the LC_{50} value of fenobucarb (0.0043%) during 2006.

The test populations of the present study exhibited slight resistance to fenobucarb which also has been in continuous use against BPH in Godavari delta since 1975. It suggests the presence of gene alleles conferring resistance to fenobucarb could be present in test populations (Jhansilakshmi *et al*., 2010a).

4.1.6 Ethofenprox

4.1.6.1. Susceptible population

During 2008-09, toxicity of ethofenprox to susceptible population of BPH showed that the LC_{50} and LC_{90} values were 0.0030 and 0.0097, respectively (Table 4.6) with a slope (b) of 2.5127 (Fig. 4.11) with no heterogeneity.

During 2009-10, the LC_{50} and LC_{90} values of ethofenprox (Table 4.6) against the susceptible BPH population were 0.0033 and 0.0108 per cent, respectively. Population was homogeneous as indicated by the chi-square test. The lcp line recorded a slope (b) of 2.4798 (Fig. 4.12).

4.1.6.2 East Godavari Population

During 2008-09, the LC_{50} and LC_{90} values of ethofenprox to the East Godavari population of BPH were 0.0042 and 0.0123 per cent, respectively (Table 4.6). The slope (b) value of lcp line of ethofenprox was 2.7070 (Fig. 4.11). The chi-square test revealed that the population used in the study was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of ethofenprox to the East Godavari population of BPH were 0.0038 and 0.0111 per cent, respectively (Table 4.6). The slope (b) value of lcp line of ethofenprox was 2.7713 (Fig. 4.12). The chi-square test revealed that the population used in the study was homogenous.

4.1.6.3 West Godavari Population

During 2008-09, the data presented in the table 4.6 indicated that the LC_{50} and LC_{90} values of ethofenprox to BPH population of West Godavari were 0.0045 and 0.0119 per cent, respectively. The slope (b) was 3.0375 (Fig. 4.11) and the population tested was homogeneous.

During 2009-10, the data presented in the table 4.6 indicated that the LC_{50} and LC_{90} values of ethofenprox to BPH population of West Godavari were 0.0045 and 0.0120 per cent, respectively. The slope (b) was 2.9541 (Fig. 4.12) and the population tested was homogeneous.

4.1.6.4 Karimnagar Population

During 2008-09, the LC_{50} and LC_{90} values of ethofenprox against BPH population of Karimnagar district were 0.0033 and 0.0098 per cent, respectively (Table 4.6). The slope (b) of the lcp line was 2.7332 (Fig. 4.11). The population of BPH used for the study was homogeneous.

During 2009-10, the LC_{50} and LC_{90} values of ethofenprox against BPH population of Karimnagar district were 0.0034 and 0.0091 per cent, respectively (Table 4.6). The slope (b) of the lcp line was 3.0102 (Fig. 4.12). The population of BPH used for the study was homogeneous.

From the present investigations it was evident that the LC_{50} values of the ethofenprox against these three test populations (East Godavari-0.0042%-0.0038%; West Godavari-0.0045%-0.0045%; Karimnagar-0.0033%-0.0034%) were slightly higher than the LC_{50} values of susceptible population (0.0030%-0.0033%) thus, acquisition of resistance to ethofenorox in test populations was negligible.

The reports available on base line toxicity of ethofenprox against BPH under laboratory are scanty. However, the present studies find support from the work of Krishnaiah *et al.* (1996) and Seetharamu *et al*. (2005) who reported that ethofenprox was very effective against rice BPH at recommended dosage (0.015%).

4.1.7 Imidacloprid

4.1.7.1 Susceptible population

During 2008-09, the toxicity of imidacloprid to susceptible population of BPH was 0.00024 and 0.0060 per cent at LC_{50} and $LC_{90,}$ respectively (Table 4.7). The population was considered to be homogenous by way of chi-square test with a 'b' value of 0.9141 (Fig. 4.13).

During 2009-10, the toxicity of imidacloprid to susceptible population of BPH was 0.00021 and 0.0039 per cent at LC_{50} and $LC_{90,}$ respectively (Table 4.7). The population was considered to be homogenous by way of chi-square test with a 'b' value of 1.0021 (Fig. 4.14).

4.1.7.2 East Godavari Population

During 2008-09, toxicity of imidacloprid to BPH population of East Godavari district showed that the LC_{50} and LC_{90} values were 0.0069 and 0.0375, respectively (Table 4.7) with a slope (b) of 1.7524 (Fig. 4.13) with no heterogeneity.

During 2009-10, the LC_{50} and LC_{90} values of imidacloprid (Table 4.7) against the BPH population of East Godavari district were 0.0073 and 0.0327 per cent, respectively. Population was homogeneous as indicated by the chi-square test. The log concentration probit line recorded a slope (b) of 1.9837 (Fig. 4.13).

4.1.7.3 West Godavari Population

During 2008-09, West Godavari population of BPH has recorded the LC_{50} and LC_{90} values 0.0112 and 0.0564 per cent, respectively (Table 4.7). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 1.8300 (Fig. 4.13).

During 2009-10, the BPH population of West Godavari districts has recorded the LC_{50} and LC_{90} values 0.0099 and 0.0572 per cent, respectively (Table 4.7). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 1.6817 (Fig. 4.14).

4.1.7.4 Karimnagar Population

During 2008-09, the toxicity of imidacloprid to BPH population of Karimnagar district was 0.0088 and 0.0483 per cent at LC_{50} and $LC_{90,}$ respectively (Table 4.7). The population was considered to be homogenous by way of chi-square test with a 'b' value of 1.7322 (Fig. 4.13).

During 2009-10, the toxicity of imidacloprid to BPH population of Karimnagar districts was 0.0088 and 0.0522 per cent at LC_{50} and $LC_{90,}$ respectively (Table 4.7). The population was considered to be homogenous by way of chi-square test with a 'b' value of 1.6656 (Fig. 4.14).

The LC_{50} and LC_{90} values of all the three test populations were higher than that of susceptible population. It is a clear indication of the acquisition of resistance in BPH populations. The present study confirms the earlier reports of Jhansilakshmi *et al*. (2010a).

The LC_{50} value of the imidacloprid recorded in the present studies to East Godavari population was higher than the LC_{50} values reported by Jhansilakshmi *et al.* (2010a) (0.0014% and 0.0059% during 2004 and 2006, respectively). The LC_{50} value of imidacloprid of West Godavari population was also higher than previous LC_{50} value (0.0041%).

The results indicated that BPH developed considerable resistance to imidacloprid. This might be due to extensive use of imidacloprid for the management of planthoppers in rice. The moderate to high level of resistance to imidacloprid to test populations appear to be due to the result of direct selection pressure of this insecticide. Some workers have also reported high level of resistance in field populations of BPH to imidacloprid (up to 811 times) in different provinces of China (Wang *et al*., 2008a., Wang *et al*., 2009 and Wen *et al*., 2009).

4.1.8 Thiamethoxam

4.1.8.1 Susceptible population

During 2008-09, the toxicity of thiamethoxam to susceptible population of BPH was 0.00074 and 0.0082 per cent at LC_{50} and $LC_{90,}$ respectively (Table 4.8). The population was considered to be homogenous by way of chi-square test with a 'b' value of 1.2224 (Fig. 4.15).

During 2009-10, the toxicity of thiamethoxam to susceptible population of BPH was 0.00078 and 0.00946 per cent at LC_{50} and $LC_{90,}$ respectively (Table 4.8). The population was considered to be homogenous by way of chi-square test with a 'b' value of 1.1822 (Fig. 4.16).

4.1.8.2 East Godavari Population

During 2008-09, it is clear from the data (Table 4.8) that East Godavari population of BPH has LC_{50} and LC_{90} values of 0.0063 and 0.0306 per cent, respectively to thiamethoxam. The slope of (b) of the lcp line was 1.8706 (Fig 4.15) with non-significance of chi-square test indicated that the BPH population tested was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of thiamethoxam against BPH population of East Godavari district were 0.0061 and 0.0383 per cent, respectively (Table 4.8). The slope of (b) of the lcp line was 1.6153 (Fig. 4.16) with non-significance of chi-square test indicating that the BPH population tested was homogenous.

4.1.8.3 West Godavari Population

During 2008-09, West Godavari population of BPH recorded the LC_{50} and LC_{90} values 0.0097 and 0.0233 per cent, respectively (Table 4.8). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 3.3958 (Fig. 4.15).

During 2009-10, the BPH population of West Godavari district has recorded the LC_{50} and LC_{90} values 0.0101 and 0.0238 per cent, respectively (Table 4.8). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 3.4725 (Fig. 4.16).

4.1.8.4 Karimnagar Population

During 2008-09, Karimnagar population of BPH recorded the LC_{50} and LC_{90} values of 0.0094 and 0.0222 per cent, respectively (Table 4.8). The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 3.4473 (Fig. 4.15).

During 2009-10, the BPH population of Karimnagar districts has recorded the LC_{50} and LC_{90} values of 0.0089 and 0.0187 per cent, respectively (Table 4.8).

The chi-square test revealed that the BPH population used in this study was homogeneous. The slope (b) value of lcp line was 3.9719 (Fig. 4.16). The LC_{50} values of all the three test populations (East Godavari-0.0061%-0.0063%; West Godavari-0.0097%-0.0101% and Karimnagar-0.0089-0.0094%) were higher than that of susceptible population (0.00074%-0.00078%). This is a clear indication of the acquisition of resistance in BPH populations.

The LC_{50} value of the thiamethoxam recorded in the present studies to East Godavari population was higher than the LC_{50} values reported by Jhansilakshmi *et al.* (2010a) (0.000398% and 0.0024%) during 2004 and 2006, respectively). The LC_{50} value of thiamethoxam recorded in the present studies to West Godavari population was higher than LC_{50} value reported by Jhansilakshmi *et al.* (2010a) (0.00157%).

The results indicated that BPH has developed considerable resistance to thiamethoxam. The low to medium level of resistance to thiamethoxam might be due to cross resistance mechanism resulting from imidacloprid application and also due to direct selection pressure of these two insecticides which were used for BPH management (Jhansilakshmi *et al.*, 2010a). Low level of cross resistance to thiamethoxam has been reported in BPH populations with high level of imidacloprid resistance in China (Wang *et al*., 2008a., Wang *et al*., 2008b., Wang *et al*., 2009 and Wang *et al*., 2010).

4.2 RELATIVE DEGREE OF RESISTANCE ACQUIRED BY *N. lugens* OF DIFFERENT DISTRICTS TO SELECTED INSECTICIDES

The BPH population obtained from East Godavari, West Godavari and Karimnagar districts were bioassayed with endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, to study the levels of insecticide resistance acquired. The level of resistance acquired was determined in comparison with the susceptible strain, baseline data and recommended concentrations.

4.2.1 Endosulfan

During 2008-09, the BPH population of West Godavari district developed 3.63, 1.72 and 1.02 fold resistance in comparison with susceptible, Karimnagar and East Godavari populations at LC_{50}; and 2.60, 2.07 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively (Table 4.9).

The BPH population of East Godavari district has developed 3.53 and 1.67 fold resistance at LC_{50} and 2.87 and 2.28 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively. Karimnagar population developed 2.11 and 1.26 fold resistance at LC_{50} and $LC_{90,}$ respectively in comparison with susceptible population.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of endosulfan (0.07%) revealed that none of the populations studied have developed resistance at $LC_{50.}$ While, the West Godavari and East Godavari populations of BPH recorded resistance ratios of 1.50 and 1.66 fold at $LC_{90,}$ respectively.

During 2009-10, on the basis of LC_{50} and LC_{90} values of endosulfan against the BPH populations of the three districts (Table 4.9) the population of West Godavari district acquired 3.16, 1.58 and 1.04 fold relative resistance at LC_{50} as compared with the BPH populations of susceptible, Karimnagar and East Godavari. But at $LC_{90,}$ the West Godavari population developed 2.52 and 2.01 fold resistance, respectively in comparison to susceptible and Karimnagar populations.

The BPH population of East Godavari district acquired 3.02 and 1.51 fold resistance at LC_{50} and 2.66 and 2.12 fold resistance at LC_{90} in comparison with the populations of susceptible and Karimnagar districts, respectively. The Karimnagar population developed 2.0 and 1.25 fold at LC_{50} and LC_{90} in comparison with susceptible population, respectively.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of endosulfan (0.07%) revealed that none of the populations studied have developed resistance at $LC_{50.}$ While, at LC_{90} the BPH populations of West Godavari and East Godavari districts developed 1.60 and 1.68 fold resistance, respectively. The variations could also result from differential selection pressures and usage of endosulfan in different districts.

The variations in the resistance ratios of test populations of BPH might be due to differential selection pressures and usage of endosulfan in different districts. Tang *et al*. (1982) also reported that the BPH population of Zhejiang province (Japan) recorded 2.4 fold resistance to γ BHC.

4.2.2 Monocrotophos

During 2008-09, a comparison of LC_{50} and LC_{90} values of monocrotophos against BPH populations of the three districts (Table 4.10) revealed that the population of West Godavari district developed 3.01, 1.29 and 1.27 fold relative resistance at LC_{50} and 1.31, 1.21 and 1.22 fold relative resistance at LC_{90} as compared with the BPH populations of susceptible, Karimnagar and East Godavari districts, respectively.

The BPH population of East Godavari district acquired 2.37 fold resistance at LC_{50} and 1.07 fold resistance at LC_{90} in comparison with susceptible population.

The Karimnagar population developed 2.34 fold resistance at LC_{50} and 1.08 fold resistance at LC_{90} in comparison with susceptible population, respectively.

Considering the base line data i.e., LC_{50} of E.G = 135.30 ppm (0.01353%); LC_{50} (W.G) = 146.60 ppm (0.0146%) (Jhansilakshmi *et al.*, 2010a), the West Godavari and East Godavari populations have developed 4.75 and 4.02 fold relative resistance at $LC_{50,}$ respectively. A comparison of recommended concentration of monocrotophos (0.0792%) with it's LC_{50} values against the three BPH populations revealed that all the three populations have not developed resistance. But at LC_{90} all the three populations acquired 1.51, 1.24 and 1.25 fold resistance, respectively.

During 2009-10, a comparison of LC_{50} and LC_{90} values of monocrotophos against BPH populations of the three districts (Table 4.10) revealed that the population of West Godavari district has developed 3.07, 1.20 and 1.21 fold relative resistance at LC_{50} and 1.49, 1.13 and 1.13 fold relative resistance at LC_{90} as compared with the BPH populations of susceptible, Karimnagar and East Godavari districts, respectively. The BPH population of East Godavari district acquired 2.5 fold resistance in comparison with susceptible population at LC_{50} and 1.31 fold resistance at LC_{90} in comparison with susceptible population, respectively.

The Karimnagar population developed 2.52 fold resistance at LC_{50}; and 1.31 and 1.31 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively.

Considering the base line data i.e., LC_{50} of E.G = 135.30 ppm (0.01353%); LC_{50} (W.G) = 146.60 ppm (0.0146%) (Jhansilakshmi *et al.,* 2010a), the West Godavari and East Godavari populations have developed 4.48 and 3.98 fold relative resistance at $LC_{50,}$ respectively.

A comparison of recommended concentration of monocrotophos (0.0792%) with their LC_{50} values against the three BPH populations revealed that all the three populations have not developed resistance. But at $LC_{90,}$ all the three populations acquired 1.50, 1.32 and 1.32 fold resistance, respectively.

It is evident from the literature that the West Godavari population of *N. lugens* showed 0.71 fold resistance to monocrotophos during 1996 (Sarupa *et al*., 1998), 1.62 fold resistance to monocrotophos selected strain of BPH during 2002 (Krishnaiah *et al*., 2002), 1.11 fold resistance during 2006 (Jhansilakshmi *et al*., 2010a), which were in conformity with the present findings.

The East Godavari population of *N. lugens* showed 1.02 fold relative resistance to monocrotophos during 2006 (Jhansilakshmi *et al*., 2010a). However, Wang and Ku (1984) observed a high level of resistance to monocrotophos in BPH population of Taiwan, 2-4 fold resistance in carbaryl selected strain of BPH to monocrotophos and 6 fold resistance to monocrotophos in Niigata strain of Japan (Ghorpade, 1990).

From the present investigations it is evident that resistance to monocrotophos in *N. lugens* has increased compared to baseline population during 2006, which might be probably due to increased selection pressure with increased use of monocrotophos in West and East Godavari districts.

A comparison of the LC_{50} values with recommended concentration (0.0792%) revealed that none of the three test BPH populations exhibited resistance to monocrotophos even though it has been in use since 1975. But the LC_{90} value was slightly higher than recommended concentration.

The broad spectrum of activity with contact and stomach toxicity along with systemic action of monocrotophos probably resulted in effective kill of the pest leaving less chances of survival and consequent development of resistance by the BPH and thus exhibited less degree of relative resistance among the BPH populations to monocrotophos.

4.2.3 Acephate

During 2008-09, the data presented in the table 4.11 revealed that the BPH population of West Godavari district developed 2.80, 1.54 and 1.15 fold resistance at LC_{50} and 1.10, 1.24 and 1.11 fold resistance at LC_{90} when compared with the BPH populations of susceptible, Karimnagar and East Godavari districts, respectively.

The BPH population of East Godavari district developed 2.42 and 1.33 fold resistance in comparison with susceptible and Karimnagar populations at $LC_{50,}$ respectively; and 1.11 fold resistance at LC_{90} in comparison with Karimnagar population.

Considering the baseline data i.e., LC_{50} (E.G) = 56.93 ppm (0.0056%); LC_{50} (W.G) = 53.65 ppm (0.0053%) (Jhansilakshmi *et al.*, 2010a), the West Godavari and East Godavari populations developed 12.0 and 9.89 fold resistance, respectively.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of acephate (0.1%) revealed that none of the populations studied have developed resistance at $LC_{50.}$ While, the West Godavari and East Godavari populations of BPH developed 1.18 and 1.06 fold resistance at $LC_{90,}$ respectively.

During 2009-10, on the basis of LC_{50} and LC_{90} values of acephate against the BPH populations of the three districts (Table 4.11) the population of West Godavari district acquired 2.79, 1.31 and 1.18 fold relative resistance at LC_{50} as compared with the BPH populations of susceptible, Karimnagar and East Godavari.

But at $LC_{90,}$ the West Godavari population developed 1.28, 1.28 and 1.08 fold resistance in comparison to susceptible, Karimnagar and East Godavari populations, respectively. The BPH population of East Godavari districts acquired 2.36 and 1.10 fold resistance at LC_{50} and 1.19 and 1.19 fold resistance at LC_{90} in comparison with the populations of susceptible and Karimnagar districts, respectively.

The Karimnagar population developed 1.31 fold resistance in comparison with susceptible population at $LC_{50.}$

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of acephate (0.1%) revealed that none of the populations studied have developed resistance at $LC_{50.}$ While at $LC_{90,}$ the BPH populations of West Godavari and East Godavari districts developed 1.26 and 1.17 fold resistance, respectively.

Studies conducted by Sarupa *et al.* (1998) also did not indicate development of resistance to acephate in BPH populations of Godavari delta during late 1998, even though they have been in use since 1975. The reason for this might be moderate effectiveness of molecules against BPH as well as lack of gene alleles in BPH populations conferring resistance to organophosphates (Jhansilakshmi *et al.*, 2010a).

However, when compared to the base line data, the resistance ratios obtained during the present studies were low to medium. It might be probably due to geographical variations in the BPH populations, genetic variations in susceptible population and increased selection pressure of acephate.

4.2.4 Phosphamidon

During 2008-09, the data presented in the table 4.12 revealed that the BPH population of West Godavari district acquired 2.22, 1.14 and 1.12 fold resistance in comparison with susceptible, Karimnagar and East Godavari populations at LC_{50}; and 1.40 and 1.04 fold resistance at LC_{90} in comparison with susceptible and East Godavari populations, respectively.

The BPH population of East Godavari district developed 1.98 and 1.02 fold resistance in comparison with susceptible and Karimnagar populations at LC_{50}; and 1.35 fold resistance at LC_{90} in comparison with susceptible population, respectively.

Karimnagar population developed 1.93 fold resistance in comparison with susceptible population; and 1.51 and 1.12 fold resistance at LC_{90} in comparison with susceptible and East Godavari populations, respectively.

Considering the baseline data i.e., LC_{50} (W.G)=43 ppm (0.0043%); (Sarupa *et al.*, 1998), the West Godavari population developed 17.06 fold resistance.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of phosphamidon (0.08%) revealed that none of the populations studied have developed resistance at $LC_{50.}$ While, the West Godavari, East Godavari and Karimnagar populations of BPH developed 1.37, 1.32 and 1.48 fold resistance at $LC_{90,}$ respectively.

During 2009-10, on the basis of LC_{50} and LC_{90} values of phosphamidon against the BPH populations of the three districts (Table 4.12) the population of West Godavari district acquired 2.30, 1.09 and 1.12 fold relative resistance in comparison with susceptible, Karimnagar and East Godavari populations at LC_{50}; 1.40 and 1.01 fold resistance at LC_{90} in comparison with susceptible and East Godavari populations, respectively.

The BPH population of East Godavari district developed 2.04 fold resistance at LC_{50} and 1.38 fold resistance at LC_{90} when compared with susceptible population.

The Karimnagar population developed 2.12 and 1.04 fold at LC_{50} and 1.53 and 1.11 fold resistance at LC_{90} when compared with the BPH populations of susceptible and East Godavari district.

Considering the baseline data of West Godavari strain given by Sarupa *et al.* (1998) (LC_{50}=43 ppm (0.0043%) the West Godavari population developed 16.79 fold resistance.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of phosphamidon (0.08%) revealed that none of the populations studied have developed resistance at $LC_{50.}$ While at $LC_{90,}$ the BPH populations of West Godavari, East Godavari and Karimnagar districts developed 1.40, 1.38 and 1.53 fold resistance, respectively.

The present findings are in conformity with Sarupa *et al*. (1998) (3.7 folds) and Sujatha and Regupathy (2003) (2.2, 1.7 and 1.3 folds).

4.2.5 Fenobucarb

During 2008-09, the data presented in the table 4.13 revealed that the BPH population of West Godavari district developed 1.39 and 1.09 fold resistance in comparison with susceptible and Karimnagar populations at LC_{50}; and 1.06 fold resistance at LC_{90} in comparison with susceptible population, respectively.

The BPH population of East Godavari district developed 1.41 and 1.10 fold resistance at LC_{50}; and 1.12 and 1.05 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively.

Karimnagar population developed 1.28 and 1.06 fold resistance at LC_{50} and LC_{90} when compared with the susceptible population, respectively.

A comparison with the baseline data i.e., LC_{50} (E.G) = 81.39 ppm (0.0081%); LC_{50} (W.G) = 43.47 ppm (0.0043%) (Jhansilakshmi *et al.*, 2010a), the BPH populations of West Godavari and East Godavari districts have developed 1.74 and 0.93 fold resistance at LC_{50}, respectively.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of fenobucarb (0.1%) revealed that none of the BPH populations studied have developed resistance.

During 2009-10, on the basis of LC_{50} and LC_{90} values of fenobucarb against the BPH populations of the three districts (Table 4.13) the population of West Godavari district acquired 1.69, 1.28 and 1.17 fold relative resistance at LC_{50} as compared with the BPH populations of susceptible, Karimnagar and East Godavari.

But at $LC_{90,}$ the West Godavari population developed 1.50, 1.16 and 1.20 fold resistance in comparison with susceptible, Karimnagar and East Godavari populations, respectively. The BPH population of East Godavari district acquired 1.44 and 1.09 fold resistance in comparison with susceptible and Karimnagar populations at $LC_{50;}$ and 1.26 fold resistance at LC_{90} in comparison with susceptible population, respectively.

The Karimnagar population developed 1.33 fold resistance in comparison with susceptible population at LC_{50}; and 1.30 and 1.03 fold resistance at LC_{90} in comparison with susceptible and East Godavari populations.

A comparison with the baseline data i.e., LC_{50} (E.G) = 81.39 ppm (0.0081%); LC_{50} (W.G) = 43.47 ppm (0.0043%) (Jhansilakshmi *et al.*, 2010a), the BPH populations of West Godavari and East Godavari districts have developed 2.04 and 0.92 fold resistance at LC_{50}, respectively.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of fenobucarb (0.1%) revealed that none of the BPH populations studied developed resistance.

The present findings are in conformity with Matsumura *et al*. (2009) who compared the LD_{50} values for the BPH strains collected from 2005 to 2007 in Japan for BPMC with those obtained before 2001 and observed no significant changes.

Chung *et al*. (1982) also reported that development of resistance to the carbamates by laboratory selection on BPH is generally slow as compared with those to organophosphates and pyrethroids.

From the present investigations it is evident that the fenobucarb is still effective against BPH populations of all the districts tested.

4.2.6 Ethofenprox

During 2008-09, the data presented in the (Table 4.14) revealed that the BPH population of West Godavari district acquired 1.50. 1.36 and 1.07 fold resistance in comparison with susceptible, Karimnagar and East Godavari populations at LC_{50}; and 1.23 and 1.21 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively.

The BPH population of East Godavari district developed 1.40 and 1.27 fold resistance in comparison with susceptible and Karimnagar populations at LC_{50}; and 1.27 and 1.26 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively. Karimnagar population developed 1.10 and 1.01 fold resistance at LC_{50} and LC_{90} in comparison with susceptible population, respectively.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of ethofenprox (0.015%) revealed that none of the populations studied have developed resistance both at LC_{50} and LC_{90}.

During 2009-10, on the basis of LC_{50} and LC_{90} values of ethofenprox against the BPH populations of the three districts (Table 4.14), the population of West Godavari districts acquired 1.36, 1.32 and 1.18 fold relative resistance in comparison with susceptible, Karimnagar and East Godavari populations at LC_{50}; 1.11 and 1.31 fold resistance at LC_{90} in comparison with susceptible and Karimnagar populations, respectively.

The BPH population of East Godavari district developed 1.15 and 1.12 fold resistance at $LC_{50;}$ and 1.02 and 1.22 fold resistance at LC_{90} when compared with susceptible and Karimnagar populations.

The Karimnagar population developed 1.03 fold resistance at LC_{50} when compared with the susceptible BPH population.

A comparison of the LC_{50} and LC_{90} values of the three populations with the recommended concentration of ethofenprox (0.015%) revealed that none of the populations studied have developed resistance at LC_{50} and LC_{90}.

From the present investigations it is evident that the LC_{50} values of the ethofenprox against three test populations were slightly higher than the LC_{50} values of susceptible population which shows that acquisition of resistance in test populations was negligible.

The reports available on base line toxicity of ethofenprox against BPH under laboratory are scanty. The present studies find support from the work of Krishnaiah *et al.* (1996) and Seetharamu *et al.* (2005) who reported that ethofenprox was very effective against rice BPH at recommended dosage (0.015%).

Krishnaiah *et al*. (2002) reported that the monocrotophos selected strain of *N. lugens* showed 2.04 fold resistance to ethofenprox, which is in conformity with the present findings.

4.2.7 Imidacloprid

On the basis of LC_{50} and LC_{90} values of imidacloprid against BPH populations of three districts obtained during 2008-09 (Table 4.15), the population of West Godavari district acquired 46.66, 1.27 and 1.62 fold resistance at LC_{50} and; 9.40, 1.16 and 1.50 resistance at LC_{90} in comparison with susceptible, Karimnagar and East Godavari populations, respectively. The BPH population of East Godavari district developed 28.75 and 6.25 fold resistance at LC_{50} and LC_{90} when compared with susceptible population.

The Karimnagar population developed 36.66 and 1.27 fold resistance at LC_{50} and 8.05 and 1.29 fold resistance at LC_{90} when compared with the susceptible and East Godavari BPH populations, respectively.

A comparison with the baseline data i.e., LC_{50} (E.G) = 14.44 ppm (0.00144%); (Jhansilakshmi *et al.,* 2010) revealed that the BPH population of East Godavari district developed 4.79 fold resistance at $LC_{50.}$ The resistance ratio of East Godavari population was reduced to 1.17 fold when compared with LC_{50} value during the year 2004 (4.79). A comparison with the baseline data i.e., LC_{50} (W.G) = 41.67 ppm (0.004167%), (Jhansilakshmi *et al.,* 2010a) indicated that the BPH population of West Godavari district has developed 2.639 fold resistance at LC_{50}.

A comparison of the LC_{50} values of the three populations with the recommended concentration of imidacloproid (0.0045%) revealed that highest resistance level was recorded in West Godavari population followed by Karimnagar and East Godavari populations with 2.49, 1.96 and 1.53 fold, respectively. A comparison of the LC_{90} values of the three populations with the recommended concentration of imidacloprid (0.0045%) revealed that highest resistance level was recorded in West Godavari population followed by Karimnagar and East Godavari populations with 12.53, 10.73 and 8.33 fold, respectively.

On the basis of LC_{50} and LC_{90} values of imidacloprid against BPH populations of three districts obtained during 2009-10 (Table 4.15), the population of West Godavari district acquired 47.14, 1.13 and 1.36 fold resistance at LC_{50} and; 14.66, 1.09 and 1.75 fold resistance at LC_{90} in comparison with susceptible, Karimnagar and East Godavari populations, respectively. The BPH population of East Godavari district developed 34.76 and 8.38 fold resistance at LC_{50} and LC_{90} when compared with susceptible population.

The Karimnagar population developed 41.90 and 1.20 fold resistance at LC_{50}; and 13.38 and 1.60 fold resistance at LC_{90} when compared with the susceptible and East Godavari BPH populations, respectively.

A comparison with the baseline data i.e., LC_{50} (W.G) = 41.67 ppm (0.004167%), (Jhansilakshmi *et al.*, 2010a) revealed that the BPH population of West Godavari district has developed 2.38 fold resistance at LC_{50}. A comparison with the baseline data i.e., LC_{50} (E.G) =14.44 ppm (0.00144%); (Jhansilakshmi *et al.*, 2010a) indicated that the BPH population of East Godavari district developed 5.07 fold resistance. The resistance ratio of East Godavari population has reduced to 1.23 fold when compared with LC_{50} value of imidacloprid (5.07) during the year 2004.

A comparison of the LC_{50} values of the three populations with the recommended concentration of imidacloproid (0.0045%) revealed that highest resistance level was recorded in West Godavari population followed by Karimnagar and East Godavari populations with 2.20, 1.95 and 1.62 fold, respectively. A comparison of the LC_{90} values of the three populations with the recommended concentration of imidacloprid (0.0045%) revealed that highest resistance level was recorded in West Godavari population followed by Karimnagar and East Godavari populations with 12.71, 11.60 and 7.26 fold, respectively.

The results indicated that BPH developed considerable resistance to imidacloprid. Intensive use of imidacloprid in almost all rice areas for more than 10 years could be the reason for the moderate to high level of resistance. The moderate to high levels of resistance to imidacloprid might be due to the result of direct selection pressure of this insecticide (Wang *et al.,* 2008c., Wang *et al*., 2009 and Jhansilakshmi *et al*,. 2010a).

Over use of insecticides is often the precursor to the development of insecticide resistance and many Asian countries rely heavily on limited number of insecticides for planthopper control (Nagata, 2002 and Sun *et al.*, 1996). Wang *et al.* (2008a) also reported dominant and intensive use of imidacloprid in a wide range of rice growing areas might be a driving force for resistance development in China.

Resistance to imidacloprid has been reported in a range of other insect species including field populations and laboratory selected strains (Zhao *et al.,* 1995., Prabhaker *et al.,* 1997., Roditakis *et al.,* 2005., Kevin *et al.,* 2008., Matsumura *et al.*, 2008 and Jhansilakshmi *et al*., 2010a).

Liang *et al*. (2010) reported that field collected population of China showed resistance to imidacloprid with resistance index varying from 98.89 to 389.19, 69 to 153.33 and 56.32 to 116.89, respectively compared with the susceptible colony from year 2006 to 2008 and the resistance level decreased in three years.

Imidacloprid like other systemic insecticides, exhibits prolonged residual activity that is likely to generate high selection pressure on the target insect for resistance development (Taylor and Georghiou, 1982).

Jhansilakshmi *et al.* (2010a) also reported that the East Godavari population of BPH developed 35.13 and 24.50 fold resistance during 2004 and 2006, respectively and the West Godavari population of BPH developed 17.28 fold resistance to imidacloprid.

Wen *et al*. (2009) from China observed high level of resistance in field populations of BPH to imidacloprid (up to 811 folds) in different provinces of China and also reported that high level of imidacloprid resistance in BPH is very unstable.

In comparison with the data of 2006, the resistance ratios in all three populations dropped slightly in 2008 and 2009. This phenomenon might be attributed to the temporary suspension of imidacloprid for planthopper control. Therefore selection pressure for imidacloprid resistance was temporarily reduced, and the resistance levels to imidacloprid in many *N. lugens* populations decreased accordingly. Probably, shift of insecticides to insect growth regulator like buprofezin or new type of chemicals like fipronil could be considered for reduction in insecticide resistance levels.

Wang *et al*. (2009) observed that even after stopping the selection pressure on imidacloprid resistant BPH for 17 generations, the population did not revert to its original susceptibility level. Instead, a moderate and stable resistance level to imidacloprid was retained in the BPH populations.

4.2.8 Thiamethoxam

A comparison of LC_{50} and LC_{90} values of thiamethoxam (Table 4.16) against the three test populations of BPH during 2008-09 revealed that the population of West Godavari district acquired 13.11, 1.03 and 1.54 fold resistance at LC_{50} in comparison with susceptible, Karimnagar and East Godavari populations, respectively.

However, the same BPH population developed 2.84 and 1.05 fold resistance when comparison with susceptible and Karimnagar populations at LC_{90}. The BPH population of East Godavari district has developed 8.51 and 3.73 fold resistance at LC_{50} and LC_{90} when compared with susceptible population; and 1.38 fold resistance at LC_{90} when compared with Karimnagar population.

The Karimnagar population developed 12.70 and 1.49 fold resistance at LC_{50} when compared with the susceptible and East Godavari BPH populations, respectively. The Karimnagar population acquired 2.70 fold resistance at LC_{90} when compared with susceptible population.

A comparison with the baseline data i.e., LC_{50} (W.G) = 15.74 ppm (0.00157%), (Jhansilakshmi *et al.,* 2010a) revealed that the BPH population of West Godavari district has developed 6.18 fold resistance at LC_{50}. A comparison with the baseline data i.e., LC_{50} (E.G) = 3.98 ppm (0.000398%) (Jhansilakshmi *et al.,* 2010a) the BPH

population of East Godavari district developed 15.82 fold resistance at $LC_{50.}$ The resistance ratio of East Godavari population has reduced to 2.62 fold when compared with LC_{50} value (15.82) of 2004.

A comparison of the LC_{50} values of the three populations with the recommended concentration of thiamethoxam (0.005%) revealed that highest resistance level was recorded in West Godavari population followed by Karimnagar and East Godavari populations with 1.94, 1.88 and 1.26 fold, respectively. A comparison of the LC_{90} values of the three populations with the recommended concentration of thiamethoxam (0.005%) revealed that highest resistance level was recorded in East Godavari population followed by West Godavari and Karimnagar populations with 6.12, 4.66 and 4.44 fold, respectively.

A comparison of LC_{50} and LC_{90} values of thiamethoxam against the three test populations of BPH during 2009-10 (Table 4.16) revealed that the population of West Godavari district acquired 12.94, 1.13 and 1.66 fold resistance at LC_{50} in comparison with susceptible, Karimnagar and East Godavari populations, respectively.

However, the same BPH population has developed 2.51 and 1.27 fold resistance in comparison with susceptible and Karimnagar populations at LC_{90}. The BPH population of East Godavari district has developed 7.82 and 4.05 fold resistance at LC_{50} and LC_{90} when compared with susceptible population; and 2.04 fold resistance at LC_{90} when compared with Karimnagar population.

The Karimnagar population developed 11.41 and 1.46 fold resistance at LC_{50} when compared with the susceptible and East Godavari BPH populations, respectively. The Karimnagar population acquired 1.98 fold resistance at LC_{90} when compared with susceptible population.

A comparison with the baseline data i.e., LC_{50} (W.G) = 15.74 ppm (0.00157%), (Jhansilakshmi *et al.,* 2010a) the BPH population of West Godavari district has developed 6.43 fold resistance at LC_{50}. A comparison with the baseline data i.e., LC_{50} (E.G) = 3.98 ppm (0.000398%) (Jhansilakshmi *et al.,* 2010a), the BPH population of East Godavari district developed 15.32 fold resistance at $LC_{50.}$ The resistance ratio of East Godavari population has reduced to 2.54 fold when compared with LC_{50} value of (15.32) 2004. It might be probably due to geographical variations in the BPH populations, genetic variations in susceptible population taken and decreased selection pressure of thiamethoxam.

A comparison of the LC_{50} values of the three populations with the recommended concentration of thiamethoxam (0.005%) revealed that highest resistance level was recorded in West Godavari population followed by Karimnagar and East Godavari populations with 2.02, 1.78 and 1.22 fold, respectively. A comparison of the LC_{90} values of the three populations with the recommended concentration of thiamethoxam (0.005%) revealed that highest resistance level was recorded in East Godavari population followed by West Godavari and Karimnagar populations with 7.66, 4.76 and 3.74 fold, respectively.

The results of the present study indicated that BPH developed low to moderate levels of resistance to thiamethoxam. In China also, very low level of cross resistance (up to 9.9 fold) to thiamethoxam has been reported in BPH populations with high level of imidacloprid resistance (Wang *et al*., 2008a., Wang *et al.*, 2008b., Wang *et al*., 2008c and Wang *et al.*, 2009). Jhansilakshmi *et al.* (2010a) observed 10.78 fold and 10.20 fold resistance to thiamethoxam in East Godavari population during 2004 and 2006 years, respectively and 6.53 fold resistance in West Godavari population during 2006.

The low to moderate level of resistance to thiamethoxam might be due to cross resistance mechanism resulting from imidacloprid application and also due to direct selection pressure of this insecticide which was deployed for BPH management along with imidacloprid (Matsumura *et al.*, 2008).

4.3 INFLUENCE OF SYNERGISTS (PBO & TPP) ON RESISTANT WEST GODAVARI STRAIN OF *N. lugens*

Synergists are very useful in elucidating resistance mechanisms, especially if they are specific inhibitors of a particular resistance conferring mechanism such as detoxification of enzymes and also play a significant role in enhancing toxicity on the resistant strain to a greater extent (Kranthi, 2005). The synergists act as useful indicators of metabolic mechanisms of resistance such as PBO for MFO systems (Chadwick, 1963), TPP for esterases (Casida, 1970). Mechanisms of insecticide resistance can be identified based on differential mortalities by combining various categories of synergists with insecticides (Prabhaker *et al*., 1988). They also can be used in understanding the effects of other xenobiotics in non target organisms (Claude and Bernard, 1993).

Synergists have an important role to play in the ongoing investigation of insecticide toxicity and mode of action and the nature of resistance mechanism. Hence, the synergists *viz.*, piperonyl butoxide (PBO) and triphenyl phosphate (TPP) were tested with endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam to know their synergistic effect on the resistant West Godavari strain of *N. lugens* during 2008-09 and 2009-10.

4.3.1 Toxicity of Piperonyl Butoxide (PBO) with Test Insecticides

4.3.1.1 Endosulfan + PBO

During 2008-09, the LC_{50} and LC_{90} values of endosulfan in combination with PBO to the West Godavari strain of *N. lugens* were 0.0035 and 0.0109 per cent, respectively (Table 4.17). The slope (b) value of lcp line for endosulfan + PBO was 2.5896 (Fig. 4.17). The chi-square test revealed that the population used in the study was homogenous.

The West Godavari strain of *N. lugens* recorded the LC_{50} and LC_{90} values of 0.0353 and 0.1053 per cent for endosulfan alone while the corresponding values in combination with PBO were 0.0035 and 0.0109 percent, respectively. The synergistic factor due to PBO at LC_{50} and LC_{90} levels was 10.08 and 9.66, respectively (Table 4.18).

During 2009-10, the LC_{50} and LC_{90} values of endosulfan in combination with PBO were 0.0040 and 0.0098, respectively (Table 4.19). The slope (b) value of lcp line for endosulfan + PBO was 3.3750 (Fig. 4.18). The chi-square test revealed that the population used in the study was homogenous. The West Godavari strain of *N. lugens* recorded the LC_{50} and LC_{90} values of 0.0339 and 0.1120 per cent for endosulfan alone, while the corresponding values in combination with PBO were 0.0040 and 0.0098 per cent, respectively. The synergistic factor due to PBO at LC_{50} and LC_{90} levels was 8.48 and 11.42, respectively (Table 4.20).

The results indicated that endosulfan in combination with PBO showed very low LC_{50} (0.0035% & 0.0040%) and LC_{90} (0.0109% & 0.0098%) as against higher values for endosulfan alone at LC_{50} (0.0353% & 0.0339%) and LC_{90} (0.1053% & 0.1120%) during 2008 and 2009, respectively.

The results showed the occurrence of synergism with synergistic ratios of 10.08 and 8.48 at LC_{50} and 9.66 and 11.42 at LC_{90} during both the seasons, respectively. The findings revealed the involvement of MFO in causing resistance in BPH to endosulfan. Synergism by mixing endosulfan with PBO was also reported in *A. gossypii* (Balakrishnan, 1998), *A. biguttula biguttula* (Chalam, 2000) and *A. gossypii* (Jhansi, 2003).

4.3.1.2 Monocrotophos + PBO

During 2008-09, it was clear from the (Table 4.17) that the LC_{50} and LC_{90} values of monocrotophos were 0.0694 and 0.1201 per cent and that of the combination of monocrotophos and PBO were 0.0035 and 0.0105 per cent, respectively against the resistant population of *N. lugens* of West Godavari district. The synergistic factors due to mixing of PBO with monocrotophos were 19.83 and 11.43 ratios at LC_{50} and LC_{90} levels, respectively (Table 4.18). The BPH population used for the study was homogeneous. The 'b' values of lcp lines of monocrotophos and monocrotophos + PBO were 5.3805 and 2.6738, respectively (Fig. 4.19).

During 2009-10, the LC_{50} and LC_{90} values were 0.0033 and 0.0109 per cent for combination of monocrotophos and PBO, respectively as against 0.0654 and 0.1190 per cent for monocrotophos alone (Table 4.19). The synergistic factors due to mixing of PBO with monocrotophos were 19.81 and 10.91 ratios at LC_{50} and LC_{90} levels, respectively (Table 4.20). The BPH population used for the study was homogeneous. The 'b' values of lcp lines of monocrotophos and monocrotophos + PBO were 4.9361 and 2.4833, respectively (Fig. 4.20).

Monocrotophos was synergised by PBO to the extent of 19.83 and 19.81 fold at $LC_{50;}$ 11.43 and 10.91 fold at LC_{90} in the resistant population of BPH from West Godavari district during 2008 and 2009, respectively. This implicates the involvement of MFOs in imparting resistance in BPH to monocrotophos to a moderate extent. Similar findings of synergism with PBO were reported by Chalam (2000) in the population of *A. biguttula biguttula* of Guntur district. Similar findings of synergism of monocrotophos by PBO in resistant population of *B. tabaci* was reported by Dittrich *et al.* (1990) to the tune of 5 and 6 fold in Nicaragua and Guatemala strains, respectively.

4.3.1.3 Acephate + PBO

During 2008-09, the data (Table 4.17) showed that the LC_{50} and LC_{90} values of acephate were 0.0640 and 0.1184 per cent and that of combination of acephate + PBO were 0.0034 and 0.0088 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of acephate with PBO were 18.82 and 13.45, respectively (Table 4.18). The BPH population was homogeneous and the regression coefficient values of lcp lines of acephate and acephate + PBO were 4.8033 and 3.1452, respectively (Fig. 4.21).

During 2009-10, the data (Table 4.19) showed that the LC_{50} and LC_{90} values of acephate were 0.0662 and 0.1256 per cent and that of combination of acephate + PBO were 0.0031 and 0.0073 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of acephate with PBO were 21.35 and 17.20, respectively. The BPH population was homogeneous and the regression coefficient values of lcp lines of acephate and acephate + PBO were 4.6164 and 3.4419, respectively (Fig. 4.22).

Acephate was synergised by PBO to the extent of 18.82 and 21.35 fold at $LC_{50;}$ 13.45 and 17.20 fold at LC_{90} in the resistant population of BPH from West Godavari district during 2008 and 2009, respectively (Tables 4.18 & 4.20). The results suggested that acephate appear to be metabolized by mixed function oxidases. A perusal of literature revealed that attempts have not been made to study the mechanisms of resistance to acephate. Therefore, further studies need to be conducted to elucidate the mechanisms of resistance to acephate operating in insect pests. However, Sun *et al.* (1987) investigated and noticed that mixed function oxidases were involved in causing resistance to organophosphorus insecticides in *A. gossypii*.

4.3.1.4 Phosphamidon + PBO

During 2008-09, the LC_{50} values were 0.0734 and 0.0046 per cent and the LC_{90} values were 0.1095 and 0.0095 per cent for phosphamidon and phosphamidon in combination with PBO, respectively (Table 4.17) against relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of phosphamidon with PBO were 15.95 and 11.52, respectively (Table 4.18). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of phosphamidon, phosphamidon + PBO were 7.3795 and 4.1078, respectively (Fig. 4.23).

During 2009-10, the LC_{50} values were 0.0722 and 0.0046 per cent and LC_{90} values were 0.1121 and 0.0113 per cent for phosphamidon and phosphamidon in combination with PBO, respectively (Table 4.19) against relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of phosphamidon with PBO were 15.69 and 9.92, respectively (Table 4.20). The BPH population used in this study was homogeneous. The 'b' values of the lcp lines of phosphamidon, phosphamidon + PBO were 6.7125 and 3.2763, respectively (Fig. 4.24).

Phosphamidon was synergised by PBO to the extent of 15.95 and 15.69 fold at $LC_{50;}$ 11.52 and 9.92 fold at LC_{90} in the resistant population of BPH from West Godavari district during 2008 and 2009, respectively (Tables 4.18 & 4.20). The results suggested that phosphamidon appear to be metabolized by mixed function oxidases. The results are in agreement with the investigations of Sun *et al.* (1987) who reported that mixed function oxidases were involved in causing resistance to organophosphorus insecticides in *A. gossypii*.

4.3.1.5 Fenobucarb + PBO

During 2008-09, it is clearly seen from the table 4.17 that the LC_{50} and LC_{90} values of fenobucarb were 0.0075 and 0.0115 per cent and that of the combination of fenobucarb and PBO were 0.0031 and 0.0074 per cent, respectively against the resistant population of *N. lugens* of West Godavari district. The synergistic factors due to mixing of PBO with fenobucarb were in the ratios of 2.41 and 1.55 at LC_{50} and LC_{90} levels, respectively (Table 4.18). The BPH population used for the study was homogeneous. The regression coefficient values of lcp lines of fenobucarb and fenobucarb + PBO were 6.8764 and 3.4832, respectively (Fig 4.25).

During 2009-10, the LC_{50} and LC_{90} values were 0.0036 and 0.0091 per cent for combination of fenobucarb and PBO, respectively as against 0.0088 and 0.0158 per cent for fenobucarb alone (Table 4.19). The synergistic factors due to mixing of PBO with fenobucarb were in the ratios of 2.44 and 1.73 at LC_{50} and LC_{90} levels, respectively (Table 4.20). The BPH population used for the study was homogeneous. The regression coefficient values of lcp lines of fenobucarb and fenobucarb + PBO were 5.0434 and 3.1995, respectively (Fig. 4.26).

Fenobucarb in combination with PBO showed synergistic factors of 2.41 and 2.44 at LC_{50}; 1.55 and 1.73 at LC_{90}, respectively during 2008 and 2009 in resistant BPH population of West Godavari district. It clearly indicated the involvement of PBO synergisable resistance due to the activity of MFO but to a lesser extent. The reports available on synergistic effect PBO in combination with fenobucarb against BPH is scanty. Limited activity of MFOs due to the combination of PBO with carbaryl was reported in *Spodoptera frugiperda* (Fahmy and Fukuto, 1970); in aphids (Jhansi, 2003).

Yoo *et al*. (2002) reported that insensitive AchE was considered to be the major resistance mechanism of the carbamate resistant strains of the brown planthopper.

4.3.1.6 Ethofenprox + PBO

During 2008-09, the data (Table 4.17) showed that the LC_{50} and LC_{90} values of ethofenprox were 0.0045 and 0.0119 per cent and the combination of ethofenprox + PBO were 0.0012 and 0.0087 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of ethofenprox with PBO were 3.75 and 1.37, respectively (Table 4.18). The BPH population was homogeneous and the regression coefficient values of lcp lines of ethofenprox and ethofenprox + PBO were 3.0375 and 1.5048, respectively (Fig. 4.27).

During 2009-10, the data (Table 4.19) showed that the LC_{50} and LC_{90} values of ethofenprox were 0.0045 and 0.0120 per cent and the combination of ethofenprox + PBO were 0.0014 and 0.0064 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of ethofenprox with PBO were 3.21 and 1.88 at LC_{50} and LC_{90}, respectively (Table 4.20). The BPH population was homogeneous and the regression coefficient values of lcp lines of ethofenprox and ethofenprox + PBO were 2.9541 and 1.9329, respectively (Fig. 4.28).

Ethofenprox in combination with PBO showed synergistic factors of 3.75 and 3.21 at LC_{50}; 1.37 and 1.88 at LC_{90}, respectively during 2008 and 2009 in resistant BPH population of West Godavari district. The results clearly revealed limited role of MFOs in causing resistance to ethofenprox in *N. lugens* over carboxyl esterases. Liu *et al*. (2002a) also reported that the PBO partially synergized ethofenprox (SR: 1.73) in resistant strain of BPH and MFO might play some role in cross resistance to ethofenprox.

4.3.1.7 Imidacloprid + PBO

During 2008-09, the LC_{50} values were 0.0112 and 0.0035 per cent and LC_{90} values were 0.0564 and 0.0091 per cent for imidacloprid and imidacloprid in combination with PBO, respectively against relatively resistant BPH population of West Godavari district (Table 4.17). The synergistic factors at LC_{50} and LC_{90} due to combination of imidacloprid with PBO were 3.2 and 6.19, respectively (Table 4.18). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of imidacloprid, imidacloprid + PBO were 1.8300 and 3.0926, respectively (Fig. 4.29).

During 2009-10, the LC_{50} values were 0.0099 and 0.0037 per cent and LC_{90} values were 0.0572 and 0.0097 per cent for imidacloprid and imidacloprid in combination with PBO, respectively against relatively resistant BPH population of West Godavari district (Table 4.19). The synergistic factors at LC_{50} and LC_{90} due to combination of imidacloprid with PBO were 2.67 and 5.89, respectively (Table 4.20). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of imidacloprid, imidacloprid + PBO were 1.6817 and 3.0860, respectively (Fig 4.30).

Imidacloprid in combination with PBO showed synergistic factors of 3.2 and 2.67 at LC_{50}; 6.19 and 5.89 at LC_{90}, respectively during 2008 and 2009 in resistant BPH population of West Godavari district. The results demonstrated that PBO exhibited obvious synergism on imidacloprid suggested that a monooxygenase might be responsible to a moderate extent for the resistance seen in West Godavari population.

Liu *et al.* (2003b) also reported that PBO showed significant synergism in some different strains of BPH and the synergism increased with resistance. Studies also revealed that the over expression of P 450 monooxygenases are responsible for detoxification of neonicotinoids (Choi *et al*., 2001 and Karunker *et al*., 2008).

Wen *et al*. (2009) reported that the imidacloprid resistance in BPH population of China was attributed mainly to the enhanced P 450 monooxygenases detoxification and could be enhanced in the same growing season if the insecticide was sprayed over and over.

4.3.1.8 Thiamethoxam + PBO

During 2008-09, the LC_{50} values were 0.0097 and 0.0028 per cent and LC_{90} values were 0.0233 and 0.0118 per cent for thiamethoxam and thiamethoxam in combination with PBO, respectively (Table 4.17) against relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of thiamethoxam with PBO were 3.46 and 1.97, respectively (Table 4.18). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of thiamethoxam, thiamethoxam + PBO were 3.3958 and 2.0385, respectively (Fig. 4.31).

During 2009-10, the LC_{50} values were 0.0101 and 0.0029 per cent and LC_{90} values were 0.0238 and 0.0120 per cent for thiamethoxam and thiamethoxam in combination with PBO, respectively against relatively resistant BPH population of West Godavari district (Table 4.19). The synergistic factors at LC_{50} and LC_{90} due to combination of thiamethoxam with PBO were 3.48 and 1.98, respectively (Table 4.20). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of thiamethoxam, thiamethoxam + PBO were 3.4725 and 2.1094, respectively (Fig. 4.32).

Thiamethoxam in combination with PBO showed synergistic factors of 3.46 and 3.48 at LC_{50}; 1.97 and 1.98 at LC_{90}, respectively during 2008 and 2009 in resistant BPH population of West Godavari district. The results indicated that PBO exhibited synergism on thiamethoxam and monooxygenases might be responsible to a moderate extent for the resistance in BPH population. These results are in agreement with the previous studies, which revealed that the over expression of P 450 monooxygenases are responsible for detoxification of neonicotinoids (Choi *et al*., 2001 and Karunker *et al*., 2008).

From the results it is evident that synergism with PBO was observed more in acephate followed by phosphamidon while it was found less with ethofenprox, thiamethoxam, imidacloprid and fenobucarb during both the seasons.

4.3.2 Toxicity of Triphenyl Phosphate (TPP) with Test Insecticides

4.3.2.1 Endosulfan + TPP

During 2008-09, the data (Table 4.21) revealed that the LC_{50} and LC_{90} values of endosulfan were 0.0353 and 0.1053 per cent and that of combination of endosulfan + TPP were 0.0053 and 0.0142 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of endosulfan with TPP were 6.66 and 7.41, respectively (Table 4.22). The BPH population was homogeneous and the regression coefficient values of lcp lines of endosulfan and endosulfan + TPP were 2.6988 and 3.0121, respectively (Fig. 4.33).

During 2009-10, the data (Table 4.23) showed that the LC_{50} and LC_{90} values of endosulfan were 0.0339 and 0.1120 per cent and that of combination of endosulfan + TPP were 0.0055 and 0.0130 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of endosulfan with TPP were 6.16 and 8.61, respectively (Table 4.24). The BPH population was homogeneous and the regression coefficient values of lcp lines of endosulfan and endosulfan + TPP were 2.4717 and 3.4482, respectively (Fig. 4.34).

Endosulfan in combination with TPP showed the synergistic factors of 6.66 & 6.16 and 7.41 & 8.61 ratios at LC_{50} and LC_{90} during both the seasons, respectively.

TPP synergised endosulfan moderately. It suggests that TPP has also been shown to induce mono oxigenases. The involvement of carboxyl esterase activity in imparting resistance to endosulfan in A. *gossypii* was also reported by O'Brien and Graves (1992).

In the present studies, the occurrence of relatively higher degree of synergism due to PBO involving the role of MFO in conferring resistance to endosulfan in BPH was clear. So, BPH acquired resistance to endosulfan largely due to MFO and slightly due to esterases.

Apart from these, certain other mechanisms of resistance to endosulfan were reported in other insects such as target site insensitivity in tobacco budworm (Khanga and Plapp, 1995), modified choline esterase and amplified carboxyl esterase in *Dysaphis planteginea* (Delorme *et al*., 1997) and higher level of protein and lipid content in cuticle (Vinson and Brazzel, 1996 and Vinson and Law, 1971).

4.3.2.2 Monocrotophos + TPP

During 2008-09, it is clearly seen from the table 4.21 that the LC_{50} and LC_{90} values of monocrotophos were 0.0694 and 0.1201 per cent and that of the combination of monocrotophos and TPP were 0.0043 and 0.0113 per cent, respectively against the resistant population of *N. lugens* of West Godavari district. The synergistic factors due to mixing of TPP with monocrotophos were 16.13 and 10.62 at LC_{50} and LC_{90} levels, respectively (Table 4.22). The BPH population used for the study was homogenous. The regression coefficient values of lcp lines of monocrotophos and monocrotophos + TPP were 5.3805 and 3.0868, respectively (Fig. 4.35).

During 2009-10, the LC_{50} and LC_{90} values were 0.0046 and 0.0122 per cent for a combination of monocrotophos and TPP, respectively as against 0.0654 and 0.1190 per cent for monocrotophos alone (Table 4.23). The synergistic factors due to mixing of TPP with monocrotophos were 14.2 and 9.75 at LC_{50} and LC_{90} levels, respectively (Table 4.24). The BPH population used for the study was homogeneous. The regression coefficient values of lcp lines of monocrotophos and monocrotophos + TPP were 4.9361 and 3.0515, respectively (Fig. 4.36).

With regards to the synergistic effect of TPP, the synergism observed was 16.13 and 14.2 fold at $LC_{50;}$ 10.62 and 9.75 fold at LC_{90} in the resistant population of BPH from West Godavari district during 2008 and 2009, respectively. Organophosphate resistance in brown planthoppers has been associated frequently with elevated levels of esterase activity (Tranter and Emden 1984 and Chen and Sun, 1994) and on at least one occasion with unaltered Acetylcholine esterase (Chung and Sun, 1981b). Chung and Sun (1983) indicated that esterase hydrolysis was involved in malathion resistance in *N. lugens* and the hydrolytic degradation also contributed to the resistance to several other organophosphorous and carbamate insecticides. The altered AchE was also verified in BPH as common mechanism of resistance to organophosphates and carbamates (Hama and Hosoda, 1983 and Miyata *et al*., 1983).

The present studies showed marginal activity of MFOs and carboxyl esterases in the acquisition of resistance by *N. lugens* to monocrotophos.

4.3.2.3 Acephate + TPP

During 2008-09, the data (Table 4.21) showed that the LC_{50} and LC_{90} values of acephate were 0.0640 and 0.1184 per cent and that of combination of acephate + TPP were 0.0045 and 0.0102 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of acephate with TPP were 14.22 and 11.60, respectively (Table 4.22). The BPH population was homogeneous and the regression coefficient values of lcp lines of acephate and acephate + TPP were 4.8033 and 3.6650, respectively (Fig. 4.37).

During 2009-10, the data (Table 4.23) showed that the LC_{50} and LC_{90} values of acephate were 0.0662 and 0.1256 per cent and that of combination of acephate + TPP were 0.0053 and 0.0097 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of acephate with TPP were 12.49 and 12.94, respectively (Table 4.24). The BPH population was homogenous and the regression coefficient values of lcp lines of acephate and acephate + TPP were 4.6164 and 4.9857 (Fig. 4.38).

With regards to the synergistic effect of TPP, the synergism observed was 14.22 and 12.49 fold at $LC_{50;}$ 11.60 and 12.94 fold at LC_{90} in the resistant population of BPH from West Godavari district during 2008 and 2009, respectively.

The present findings are in conformity with the findings of Tranter and Emden (1984) and Chen and Sun (1994) who reported that the organophosphate resistance in brown planthoppers was associated with elevated levels of esterase activity. Chung and Sun (1981b) reported that altered acetylcholine esterase also contributes to BPH resistance.

The present results conclusively showed marginal activity of MFOs and carboxyl esterases in the acquisition of resistance by *N. lugens* to acephate.

4.3.2.4 Phosphamidon + TPP

During 2008-09, the LC_{50} values were 0.0734 and 0.0569 per cent and LC_{90} values were 0.1095 and 0.0959 per cent for phosphamidon and phosphamidon in combination with TPP, respectively (Table 4.21) against the relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of phosphamidon with TPP were 1.28 and 1.14, respectively (Table 4.22).

The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of phosphamidon, phosphamidon + TPP were 7.3795 and 5.6605, respectively (Fig. 4.39).

During 2009-10, the LC_{50} values were 0.0722 and 0.0559 per cent and LC_{90} values were 0.1121 and 0.0917 per cent for phosphamidon and phosphamidon in combination with TPP, respectively (Table 4.23) against the relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of phosphamidon with TPP were 1.29 and 1.22, respectively (Table 4.24). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of phosphamidon, phosphamidon + TPP were 6.7125 and 5.9649, respectively (Fig. 4.40).

TPP synergised phosphamidon slightly, indicating the involvement of esterases to a lesser extent in imparting resistance to phosphamidon.

The present results showed that the BPH acquired resistance to phosphamidon due to MFO and slightly due to esterases. The present findings are in conformity with the findings of Tranter and Emden (1984) and Chen and Sun (1994) who reported that the organophosphate resistance in brown planthoppers was associated with elevated levels of esterase activity. The altered AchE was also verified in BPH is common mechanism of resistance to organophosphates (Hama and Hosoda, 1983 and Miyata *et al*., 1983). Further studies need to be conducted to elucidate the mechanisms of resistance to phosphamidon operating in insect pests.

4.3.2.5 Fenobucarb + TPP

During 2008-09, it is clearly seen from the table 4.21 that the LC_{50} and LC_{90} values of fenobucarb were 0.0075 and 0.0115 per cent and that of the combination of fenobucarb and TPP were 0.0047 and 0.0086 per cent, respectively against the resistant population of *N. lugens* of West Godavari district. The synergistic factors due to mixing of TPP with fenobucarb were 1.59 and 1.33 at LC_{50} and LC_{90} levels, respectively (Table 4.22). The BPH population used for the study was homogeneous. The regression coefficient values of lcp lines of fenobucarb and fenobucarb + TPP were 6.8764 and 4.8773, respectively (Fig. 4.41).

During 2009-10, the LC_{50} and LC_{90} values were 0.0051 and 0.0104 per cent for a combination of fenobucarb and TPP, respectively as against 0.0088 and 0.0158 per cent for fenobucarb alone (Table 4.23). The synergistic factors due to mixing of TPP with fenobucarb were 1.72 and 1.51 at LC_{50} and LC_{90} levels, respectively (Table 4.24). The BPH population used for the study was homogeneous. The regression coefficient values of lcp lines of fenobucarb and fenobucarb + TPP were 5.0434 and 4.1615, respectively (Fig. 4.42).

TPP synergised fenobucarb slightly, indicating the involvement of esterases to a lesser extent in imparting resistance to fenobucarb.

Liu *et al*. (2003b) also reported that TPP moderately synergised fenobucarb (SR: 2.17) in the resistant strain of BPH. Chung and Sun (1983) indicated that esterase hydrolysis was involved in malathion resistance in *N. lugens* and the hydrolytic degradation contributed to the resistance to several other organophosphorous and carbamate insecticides.

Devonshire and Moores (1982) also reported that a carboxyl esterase with broad substrate specificity caused organophosphorous, carbamate and pyrethroid resistance in *Myzus persicae*. The other resistance mechanisms like insensitive AchE was observed in BPH as common mechanism of resistnce to organophosphates and carbamates (Russell, 1980., Hama and Hosoda, 1983., Miyata *et al*., 1983., Sun *et al*., 1984b and Yoo, 2002).

4.3.2.6 Ethofenprox + TPP

During 2008-09, the data (Table 4.21) showed that the LC_{50} and LC_{90} values of ethofenprox were 0.0045 and 0.0119 per cent and that of combination of ethofenprox + TPP were 0.0025 and 0.0072 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of ethofenprox with TPP were 1.8 and 1.65, respectively (Table 4.22). The BPH population was homogeneous and the regression coefficient values of lcp lines of ethofenprox and ethofenprox + TPP were 3.0375 and 2.7310, respectively (Fig. 4.43).

During 2009-10, the data (Table 4.23) showed that the LC_{50} and LC_{90} values of ethofenprox were 0.0045 and 0.0120 per cent and that of combination of ethofenprox + TPP were 0.0023 and 0.0089 per cent, respectively against the relatively resistant BPH population of West Godavari district. The synergistic factors due to mixing of ethofenprox with TPP were 1.95 and 1.34, respectively (Table 4.44). The BPH population was homogeneous and the regression coefficient values of lcp lines of ethofenprox and ethofenprox + TPP were 2.9541 and 2.2337, respectively (Fig. 4.44).

Ethofenprox in combination with TPP showed synergistic factors of 1.80 and 1.95 at LC_{50}; 1.65 and 1.34 at LC_{90}, respectively during 2008 and 2009 and in resistant BPH population of West Godavari district. Dai and Sun (1984) reported that carboxyl esterases are responsible for resistance in BPH. The present findings are in conformity with the findings of Liu *et al*. (2003b) who reported that TPP could significantly inhibit esterase activity in the resistant strain of BPH. Vantas *et al.* (2001) reported that elevated glutathione S transferase with a predominant peroxidase function is responsible for resistance to the pyrethroid insecticide, lambda cyhalothrin.

4.3.2.7 Imidacloprid + TPP

During 2008-09, the LC_{50} values were 0.0112 and 0.0102 per cent and LC_{90} values were 0.0564 and 0.0502 per cent for imidacloprid and imidacloprid in combination with TPP, respectively (Table 4.21) against the relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of imidacloprid with TPP were 1.09 and 1.12, respectively (Table 4.22). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of imidacloprid, imidacloprid + TPP were 1.8300 and 1.8513, respectively (Fig. 4.45).

During 2009-10, the LC_{50} values were 0.0099 and 0.0091 per cent and LC_{90} values were 0.0572 and 0.0471 per cent for imidacloprid and imidacloprid in combination with TPP, respectively (Table 4.23) against relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of imidacloprid with TPP were 1.08 and 1.21, respectively (Table 4.44). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of imidacloprid, imidacloprid + TPP were 1.6817 and 1.7943, respectively (Fig. 4.46).

Imidacloprid in combination with TPP showed synergistic factors of 1.09 and 1.08 at LC_{50}; 1.12 and 1.21 at LC_{90}, respectively during 2008 and 2009 in resistant BPH population of West Godavari district. The results demonstrated that TPP exhibited no synergism on imidacloprid. Based on the synergistic effect of TPP, it could be stated that esterases were not involved in the detoxification and consequently the resistance of imidacloprid in *N. lugens*.

Liu *et al.* (2003b) also reported TPP had no synergism on imidacloprid and the esterase and glutathione S-transferase play little role in imidacloprid detoxification. on the contrary, Graham and Hemingway (2000) reported that the major resistance mechanism in the BPH involves over production of esterases.

Liu *et al.* (2005) observed that imidacloprid resistant population of BPH exhibited cross resistance to only those insecticides targeting on acetylcholine receptors. The lack of cross-resistance to other insecticide classes and the lack of marked synergism by inhibitors of detoxifying enzymes suggested that resistance might be due to mutation within the target site of imidacloprid rather than due to enhanced detoxification.

4.3.2.8 Thiamethoxam + TPP

During 2008-09, the LC_{50} values were 0.0097 and 0.0094 per cent and LC_{90} values were 0.0233 and 0.0223 per cent for thiamethoxam and thiamethoxam in combination with TPP, respectively (Table 4.21) against the relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of thiamethoxam with TPP were 1.03 and 1.03, respectively (Table 4.22). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of thiamethoxam, thiamethoxam + TPP were 3.3958 and 3.4092, respectively (Fig. 4.47).

During 2009-10, the LC_{50} values were 0.0101 and 0.0081 per cent and LC_{90} values were 0.0238 and 0.0200 per cent for thiamethoxam and thiamethoxam in combination with TPP, respectively (Table 4.23) against the relatively resistant BPH population of West Godavari district. The synergistic factors at LC_{50} and LC_{90} due to combination of thiamethoxam with TPP were 1.24 and 1.19, respectively (Table 4.24). The BPH population used in this study was homogeneous. The regression coefficient values of the lcp lines of thiamethoxam, thiamethoxam + TPP were 3.4725 and 3.2778, respectively (Fig. 4.48).

Thiamethoxam in combination with TPP showed synergistic factors of 1.03 and 1.24 at LC_{50}; 1.03 and 1.19 at LC_{90}, respectively during 2008 and 2009 in resistant BPH population of West Godavari district. The results demonstrated that TPP exhibited no synergism on thiamethoxam. Based on the synergistic effect of TPP, it could be stated that esterases were not involved in the detoxification and consequently the resistance of thiamethoxam in *N. lugens*.

The results are in conformity with the findings of Liu *et al*. (2003b) who reported that TPP had no synergism on imidacloprid, which has same mode of action like thiamethoxam. The results demonstrated that other resistance mechanisms might have been involved in resistance to thiamethoxam.

From the above results, it is evident that synergism with TPP was observed more in monocrotophos followed by acephate, endosulfan, ethofenprox, fenobucarb, phosphamidon, imidacloprid and thiamethoxam at LC_{50} level revealing that the levels of resistance to monocrotophos, acephate and endosulfan could be brought down successfully with the synergist TPP.

4.4 MANAGEMENT OF INSECTICIDE RESISTANT POPULATION OF *N. lugens* WITH NEW INSECTICIDES

The new insecticides with different modes of action *viz.*, buprofezin 25 SC, ethiprole 10 EC, imidacloprid + ethiprole (40+40)-80 WG and pymetrozine 50 WG were tested against the resistant strain of *N. lugens* of West Godavari population to know the susceptibility of the resistant strain to the new insecticides and in turn for their utility in the management of the resistant population. Relative toxicity was calculated in comparison with test insecticides *viz.*, endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam by dividing LC_{50} and LC_{90} levels of these insecticides with corresponding values of new insecticides.

4.4.1 Buprofezin

4.4.1.1 Toxicity of Buprofezin 25 SC against the Relatively Resistant *N. lugens* Population of West Godavari District.

The LC_{50} and LC_{90} values of buprofezin to the insecticide resistant West Godavari strain of *N. lugens* during 2008-09 were 0.00014 and 0.00091, respectively (Table 4.25). The slope (b) value of lcp line of buprofezin was 1.5850 (Fig. 4.49). The chi-square test revealed that the population used in the study was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of buprofezin were 0.00015 and 0.00070, respectively (Table 4.25). The slope (b) value of lcp line of buprofezin was 1.9117 (Fig.4.50). The chi-square test revealed that the population used in the study was homogenous. Among the new insecticides buprofezin was first in its position at LC_{50} and LC_{90} during both the years of study at five days after treatment (Table 4.25).

4.4.1.2 Relative Toxicity of Buprofezin 25 SC in Comparison with Other New Test Insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District

During 2008-09, the relative toxicity of buprofezin at LC_{50} and LC_{90} against the resistant West Godavari strain of *N. lugens* was 2.5 and 1.64; 1.28 and 1.64; 1.29 and 1.99 times more than that of ethiprole, pymetrozine and imidacloprid + ethiprole, respectively (Tables 4.26, 4.29 and Fig. 4.51).

While, during 2009-10 at LC_{50} and LC_{90} values of buprofezin were 2.33 and 2.42; 1.26 and 2.14; 1.33 and 2.14 times more toxic than ethiprole, pymetrozine and imidacloprid + ethiprole, respectively (Table 4.26 & Fig. 4.52).

4.4.1.3 Relative Toxicity of Buprofezin 25 SC in Comparison with Certain Commonly Used Test Insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, when the toxicity of buprofezin was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 252.14, 495.71, 457.14, 524.29, 53.57, 32.14, 80.00 and 69.29 times at LC_{50} and 115.71, 131.98, 130.11, 120.33, 12.64, 13.08, 61.98 and 25.60 at LC_{90}, respectively (Table 4.27 & Fig. 4.53).

During 2009-10, when the toxicity of buprofezin was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 226.0, 436, 441.33, 481.33, 58.67, 30.00, 66.00 and 67.33 times at LC_{50} and 160.0, 170.0, 179.43, 160.14, 22.57, 17.14, 81.71 and 34.00 times at LC_{90}, respectively (Table 4.28 & Fig. 4.54).

In the present investigations, the LC_{50} and LC_{90} values of buprofezin were very less and it was found to be the best insecticide in its toxicity among the new insecticides with the highest relative toxicity against resistant strain of *N. lugens* when compared to conventional insecticides.

The present findings are in accordance with the reports available regarding the efficacy of buprofezin against BPH of Rice (Heinrichs *et al*., 1984., Kendappa *et al*., 2005., Fukuda *et al*., 2007 and Shashank, 2009).

4.4.2 Imidacloprid + ethiprole (40+40)-80 WG

4.4.2.1 Toxicity of Imidacloprid + ethiprole against the Relatively Resistant *N. lugens* Population of West Godavari District.

The LC_{50} and LC_{90} values of imidacloprid + ethiprole to the insecticide resistant West Godavari strain of *N. lugens* during 2008-09 were 0.00018 and 0.001816, respectively (Table 4.25). The slope (b) value of lcp line of Imidacloprid + ethiprole was 2.2742. (Fig. 4.49). The chi-square test revealed that the population used in the study was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of imidacloprid + ethiprole were 0.00020 and 0.0015, respectively (Table 4.25). The slope (b) value of lcp line of imidacloprid + ethiprole was 1.4520 (Fig. 4.50). The chi-square test revealed that the population used in the study was homogenous.

4.4.2.2 Relative Toxicity of Imidacloprid + ethiprole (40+40)-80 WG in Comparison With other New test Insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, the relative toxicity of imidacloprid + ethiprole (40+40)-80 WG against the resistant West Godavari strain of *N. lugens* at LC_{50} and LC_{90} values indicated that it was 1.94 times more toxic at LC_{50} as compared to ethiprole but was less toxic than pymetrozine and buprofezin by 0.1 and 0.77 fold at LC_{50}, respectively. (Tables 4.26, 4.29 and Fig. 4.51).

During 2009-10, Imidacloprid + ethiprole was 1.75 and 1.13 times more toxic at LC_{50} and LC_{90} values than ethiprole. It was found inferior to pymetrozine and buprofezin at LC_{50} and on par with pymetrozine at LC_{90} (Tables 4.26, 4.29 and Fig. 4.52).

4.4.2.3 Relative Toxicity of Imidacloprid + ethiprole (40+40)-80 WG in Comparison with Certain Commonly Used Test insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, when the toxicity of this insecticide was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 196.11, 385.56, 355.56, 407.78, 41.67, 25.00, 62.22 and 53.89 times at LC_{50} and 57.98, 66.13, 65.20, 60.30, 6.33, 6.55, 31.06 and 12.83 at LC_{90}, respectively (Table 4.27 and Fig 4.53).

During 2009-10, when the toxicity of this insecticide was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 169.50, 327.0, 331.0, 361.0, 44.0, 22.5, 49.50 and 50.50 times at LC_{50} and 74.67, 79.33, 83.73, 74.73, 10.53, 8.0, 38.13 and 15.87 times at LC_{90}, respectively (Table 4.28 and Fig. 4.54).

The combination product, imidacloprid+ethiprole showed better efficacy against BPH.

Better efficacy of imidacloprid alone was reported by Reddy and Krishnaiah (2003) and Seetharamu *et al*. (2005). Krishnaiah *et al*. (2004) reported that ethiprole at 50 ppm (0.005%) showed good persistent toxicity and the fumigant action of ethiprole also contributed towards the kill of BPH. Sekh *et al.* (2007) reported that the combination product of ethiprole and imidacloprid were effective in managing BPH of rice under field conditions. Jhansilakshmi *et al* (2010b) reported that imidacloprid+ethiprole exhibited excellent initial and persistence toxicity against WBPH and GLH.

4.4.3 Ethiprole 10 SC

4.4.3.1 Toxicity of Ethiprole 10 SC against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, the LC_{50} and LC_{90} values of ethiprole were 0.00035 and 0.0015 per cent, respectively (Table 4.25) to the resistant population of *N. lugens* of West Godavari district. The lcp line has slope value (b) of 1.9994 (Fig. 4.49). The chi-square test revealed non segregation of phenotypes.

During 2009-10, the LC_{50} and LC_{90} values of ethiprole were 0.00035 and 0.0017, respectively (Table 4.25). The slope (b) value of lcp line of ethiprole was 1.8680 (Fig. 4.50). The chi-square test revealed that the population used in the study was homogenous.

4.4.3.2 Relative Toxicity of Ethiprole 10 SC in Comparison With other New Test Insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, it was least effective among the new molecules tested and was inferior and less toxic than buprofezin, imidacloprid + ethiprole and pymetrozine at LC_{50}. However, it was slightly toxic than imidacloprid + ethiprole at LC_{90} (Tables 4.26, 4.29 and Fig. 4.51).

While, during 2009-10, it was least effective among the new molecules tested and was inferior and less toxic than buprofezin, imidacloprid + ethiprole and pymetrozine both at LC_{50} and LC_{90} (Tables 4.26, 4.29 and Fig. 4.52).

4.4.3.3 Relative Toxicity of Ethiprole 10 SC in Comparison with the Certain Commonly Used Test Insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, the toxicity of Ethiprole was compared with the toxicity of some commonly used insecticides *viz.*, endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 100.86, 198.29, 182.86, 209.71, 21.43, 12.86, 32.00 and 27.71 times at LC_{50} and 70.20, 80.07, 78.93, 73.00, 7.67, 7.93, 37.60 and 15.53 at LC_{90}, respectively (Table 4.27 and Fig. 4.53).

During 2009-10, when the toxicity of this insecticide was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 96.86, 186.86, 189.14, 206.29, 25.14, 12.86, 28.29 and 28.86 times at LC_{50} and 65.88, 70.00, 73.88, 65.94, 9.29, 7.06, 33.65 and 14.00 times at LC_{90}, respectively (Table 4.28 and Fig. 4.54).

The results of the present study are in accordance with the findings of earlier investigations revealing the efficacy of ethiprole against BPH (Varma *et al.,* 2003., Kumaran *et al*., 2007 and Sekh *et al*., 2007).

Jhansilakshmi *et al.* (2010a) recorded LC_{50} of 0.0001% (1.00 ppm) for East Godavari population. The insecticide belongs to phenyl pyrazole group, exhibits entirely different mode of action i.e. by acting as potential blockers of gamma amino butyric acid (GABA) regulating chloride channels in nerve membrane of insect central nervous system. This might be the reason for no cross resistance to phenylpyrazoles in resistant populations from West Godavari district of Andhra Pradesh.

The reason behind the effectiveness of ethiprole is its fumigant action, effective upward translocation and ovicidal action against planthoppers (Krishnaiah *et al*., 2004).

4.4.4 Pymetrozine 50 WG

4.4.4.1 Toxicity of Pymetrozine 50 WG against the Relatively Resistant *N. lugens* Population of West Godavari District.

The LC_{50} and LC_{90} values of pymetrozine to the insecticide resistant West Godavari strain of *N. lugens* during 2008-09 were 0.00018 and 0.0015, respectively (Table 4.25). The slope (b) value of lcp line was 1.4014 (Fig.4.49). The chi-square test revealed that the population used in the study was homogenous.

During 2009-10, the LC_{50} and LC_{90} values of pymetrozine were 0.00019 and 0.0015, respectively (Table 4.25). The slope (b) value of lcp line was 1.4270 (Fig. 4.50). The chi-square test revealed that the population used in the study was homogenous.

Among the new insecticides pymetrozine was second in its toxicity at LC_{50} and LC_{90} levels during both the years of study.

4.4.4.2 Relative Toxicity of Pymetrozine 50 WG in Comparison With Other New Test Insecticides against the Relatively Resistant *N. lugens* population of West Godavari District.

During 2008-09 the relative toxicity of pymetrozine against the resistant West Godavari strain of *N. lugens* at LC_{50} and LC_{90} values indicated that it was 1.94 and 1.00; 1.00 and 1.21 times more toxic than ethiprole and imidacloprid+ethiprole, respectively. However, it was inferior to buprofezin by 0.77 and 0.60 fold at LC_{50} and LC_{90}, respectively. The toxicity was on par with imidacloproid + ethiprole at LC_{50} but was slightly more toxic at LC_{90} (Tables 4.26, 4.29 and Fig. 4.51).

During 2009-10, at LC_{50} and LC_{90} values pymetrozine was 1.84 and 1.13; 1.05 and 1.0 times more toxic than ethiprole and imidacloprid + ethiprole, respectively. It was inferior to buprofezin both at LC_{50} and LC_{90} (Tables 4.26, 4.29 and Fig. 4.52)

4.4.4.3 Relative Toxicity of Pymetrozine 50 WG in Comparison With the Certain Commonly Used Test Insecticides against the Relatively Resistant *N. lugens* Population of West Godavari District.

During 2008-09, when the toxicity of pymetrozine was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 196.11, 385.56, 355.56, 407.78, 41.67, 25.00, 62.22 and 53.89 times at LC_{50} and 70.20, 80.07, 78.93, 73.00, 7.67, 7.93, 37.60 and 15.53 at LC_{90}, respectively (Table 4.27 and Fig. 4.53).

During 2009-10, when the toxicity of this insecticide was compared with the toxicity of some commonly used insecticides *viz.,* endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, it was more toxic by 178.42, 344.21, 348.42, 380.0, 46.32, 23.68, 52.11 and 53.16 times at LC_{50} and 74.67, 79.33, 83.73, 74.73, 10.53, 8.00, 38.13 and 15.87 times at LC_{90}, respectively (Table 4.28 and Fig. 4.54).

Polston and Sherwood (2003) reported that pymetrozine provided protection against tomato yellow leaf curl virus by viruliferous white flies, *Bemisia tabaci* (Gennadius). The superior efficacy of pymetrozine was also reported by Wyss and Balsinger (1997)., Slosser *et al*. (2000) and Muralibaskaran *et al*. (2009) against different pests.

4.5 EFFECT OF INSECTICIDE RESISTANCE ON CERTAIN BIOLOGICAL PARAMETERS OF *N. lugens*

The evolution and spread of insecticide resistance is influenced by biological and genetic factors (Georghiou and Taylor, 1977). The present study was conducted to assess the extent of change in biological characteristics as a result of insecticide resistance. The different biological parameters such as egg period, No. of progeny, duration of nymphal instars and longevity of adults were recorded in East Godavari, West Godavari, Karimnagar and susceptible BPH populations and the data were presented in tables 4.30 to 4.33 and figures 4.56 to 4.58. The average temperature, relative humidity during the study period was 27-30ºC and 70-80%.

4.5.1 Duration of Nymphal Instars

During 2008-09**,** there were five instars in BPH populations of all the districts. The mean duration of the first, second, third, fourth and fifth nymphal instars were 3.04, 2.20, 2.40, 2.32 and 3.24 days in susceptible population; 3.20, 2.24, 2.72, 2.72 and 3.68 days in East Godavari population ;3.36, 2.24, 2.52, 2.88 and 3.68 days in West Godavari population and 3.32, 2.32, 2.36, 2.84 and 3.72 days in Karimnagar population, respectively (Table 4.30). There were no significant differences in the mean duration of different instars of BPH population of all the locations. The mean total nymphal periods of susceptible, East Godavari, West Godavari and Karimnagar populations were 13.2, 14.56, 14.68 and 14.56 days, respectively (Table 4.32). There were no significant differences in the mean total nymphal period.

During 2009-10**,** there were five instars in BPH populations of all the districts. The mean duration of the first, second, third, fourth and fifth nymphal instars were 2.92, 1.96, 2.32, 2.12 and 3.16 days in susceptible population; 3.20, 2.12, 2.48, 2.64, and 3.80 days in East Godavari population; 3.28, 2.44, 2.52, 2.84, and 3.68 days in West Godavari population and 3.16, 2.40, 2.56, 2.96 and 3.72 days in Karimnagar

population, respectively (Table 4.31). There were no significant differences in the mean duration of different instars of BPH population of all the locations. The mean total nymphal periods of susceptible, East Godavari, West Godavari and Karimnagar populations were 12.48, 14.24, 14.76 and 14.80 days, respectively (Table 4.33). Significant differences in mean total nymphal periods of different BPH populations were observed. The mean nymphal period of susceptible population was significantly less (12.48 days) as compared to other BPH populations.

The results revealed that there were no significant differences in the mean duration of different instars and total nympal periods of BPH populations of all the locations, probably because of low degree of resistance acquired by the test populations. But, during 2009 significant differences in mean total nymphal periods of different BPH populations were observed. The mean nymphal period of susceptible population was significantly less (12.48 days) as compared to other BPH populations.

The present results also revealed that all the test populations of BPH developed low levels of resistance to cyclodiene, organophosphorous, carbamates, non ester pyrethroids and low to moderate level of resistance to neonicotinoids. The results were in conformity with the findings of Feng *et al.* (1996), who reported that there were no significant differences in vitality and reproductivity between monocrotophos resistant populations and susceptible ones.

4.5.2 Egg period

The mean egg period was 6.20, 6.56, and 6.92 and 6.92 days for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively during 2008-09. The egg period was significantly less in the case of susceptible population (Table 4.32 and Fig. 4.57).

During 2009-10, the mean egg period was 6.24, 6.84, 6.88 and 6.84 days for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively. The egg period was significantly less in the case of susceptible population (Table 4.33 and Fig. 4.58).

The BPH populations of different districts recorded significantly more egg periods compared to the susceptible population. The results are in conformity with the findings of Liu *et al*. (2003a), who reported that imidacloprid resistant strains of BPH showed developmental disadvantages including prolonged egg duration, lower nymphal survival rate, lower adult emergence rate and shorter female duration and reproductive disadvantages such as lower copulation rate, fecundity and hatchability.

4.5.3 Number of Progeny

The mean fecundity was 183, 167, 164 and 169 nymphs per female for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively, during 2008-09 (Table 4.32 and Fig. 4.57).

There were no significant differences in the mean number of progeny of a single female of BPH populations of susceptible, East Godavari, West Godavari and Karimnagar populations.

The mean fecundity was 151, 148, 135 and 130 nymphs per female for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively, during 2009-10 (Table 4.33 and Fig. 4.58). There were no significant differences in the mean number of progeny of a single female of BPH populations of susceptible, East Godavari, West Godavari and Karimnagar populations.

Feng *et al*. (1996) also reported that there were no significant difference in vitality and reproductivity between monocrotophos resistant populations and susceptible population.

4.5.4 Pre-Oviposition Period

During 2008-09, there was no significant difference with respect to pre-oviposition period of BPH populations of susceptible, East Godavari, West Godavari and Karimnagar districts. The average pre-oviposition period was 3.04, 3.40, 3.56 and 3.52 days for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively and the range was 2 - 4 days (Table 4.32 and Fig. 4.57).

During 2009-10, significant differences with respect to pre-oviposition period of BPH were not observed among susceptible, East Godavari, West Godavari and Karimnagar populations. The average pre-oviposition period was 3.08, 3.36, 3.72 and 3.48 days for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively and the range was 2 - 4 days (Table 4.33 and Fig. 4.58).

There was no significant difference with respect to pre-oviposition period of BPH of susceptible, East Godavari, West Godavari and Karimnagar populations and the range was 2 - 4 days. Similarly, Barbara (1987) reported that the pre-reproductive period and nymphal development of aphids could not be related to level of organophosphorus resistance.

4.5.5 Oviposition Period

During 2008-09, there were no significant differences with respect to oviposition period of BPH of susceptible, East Godavari, West Godavari and Karimnagar populations.

The average oviposition period was 4.40, 3.84, 3.92 and 3.92 days for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively and the range was 3 - 5 days (Table 4.32 and Fig. 4.57).

During 2009-10, the oviposition period of BPH did not differ significantly among the susceptible, East Godavari, West Godavari and Karimnagar populations. The average oviposition period was 4.32, 4.00, 3.96 and 3.80 days for susceptible, East Godavari, West Godavari and Karimnagar populations, respectively and the range was 3 - 6 days (Table 4.33 and Fig. 4.58).

There were no significant differences with respect to oviposition period of BPH of susceptible, East Godavari, West Godavari and Karimnagar populations and the range was 3 - 6 days. Similarly, Barbara (1987) reported that the pre-reproductive period and nymphal development could not be related to level of organophosphorus resistance.

4.5.6 Adult Longevity

During 2008-09, the average adult longevity of brachypterous female was 19.36 days with a range from 15 - 24 days for susceptible population and 18.36 days with a range from 15 - 24 days for East Godavari Population and 17.08 days with a range from 13 - 25 days for West Godavari population and 18.20 days with a range from 13 - 24 days for Karimnagar population.

The mean longevity of macropterous males was 17.36 days with a range from 15 - 23 days for susceptible population and 17.00 days with range from 14 - 22 days for East Godavari population and 16.84 days with a range from 12 - 23 days for West Godavari population and 16.80 days with a range from 12 - 22 days for Karimnagar population (Table 4.32 and Fig. 4.57).

During 2009-10, the average adult longevity of brachypterous female was 18.44 days with a range from 15 - 24 days for susceptible population; 17.80 days with a range from 14 - 25 days for East Godavari Population; 18.12 days with a range from 10 - 24 days for West Godavari population and 17.20 days with a range from 13 - 24 days for Karimnagar population. The mean longevity of macropterous males was 18.40days with a range from 15 - 23 days for susceptible population; 17.0 days with range from 12 - 23 days for East Godavari population; 17.08 days with a range from 13 - 24 days for West Godavari population and 17.24 days with a range from 12-23 days for Karimnagar population (Table 4.33 and Fig. 4.58).

4.5.7 Total Life Cycle

No significant differences were recorded between the different populations in respect of the total life cycle during 2008-09. The mean total life cycle of BPH was observed to be 38.62 days for susceptible population; 39.48 days for East Godavari population; 38.68 days for West Godavari population; 39.68 days for Karimnagar population, respectively (Table 4.32 and 4.57).

Significant differences were not recorded between the different populations in respect to the total life cycle during 2009-10. The mean total life cycle of BPH was observed to be 37.16 days for susceptible population; 38.88 days for East Godavari population; 39.76 days for West Godavari population and 38.84 days for Karimnagar population, respectively (Table 4.33 and Fig. 4.58).

In respect of many biological parameters, there were no variations probably because of low degree of resistance acquired by the BPH populations of different districts.

Table 2.1. Global Status of Insecticide Resistance in *N. lugens.*

Insecticide group & Insecticide	Resistance factor	Country/Area	Reference
Organochlorines			
γ BHC	2.4	Zhejiang province (Japan)	Tang *et al.* (1982)
Organophosphates			
Malathion	6.8	Zhejiang province (Japan)	Tang *et al*. (1982)
Parathion	3.0	Zhejiang province (Japan)	-do-
Carbaryl	4.0	Kagawa prefecture (Japan)	Kassai and Ozaki (1984)
-do-	1.00	West Godavari (A.P)	Sarupa *et al.* (1998)
Monocrotophos	0.71	West Godavari (A.P)	Sarupa *et al.* (1998)
-do-	1.62	Andhra Pradesh (India)	Krishnaiah *et al*. (2002)
-do-	1.02	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	1.11	West Godavari (A.P)	-do-
Chlorpyriphos	1.16	West Godavari (A.P)	Sarupa *et al.* (1998)
Quinalphos	0.70	-do-	-do-
Phosphamidon	3.07	-do-	-do-
-do-	2.2	Andhra Pradesh (India)	Krishnaiah *et al*. (2002)
Acephate	0.84	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	0.79	West Godavari (A.P)	-do-
Carbamates			
MIPC	6.1	Taiwan	Lin *et al.* (1979)
MTMC	8.0	-do-	-do-
Fenobucarb	2.30	West Godavari (A.P)	Sarupa *et al.* (1998)
-do-	93	Japan	Yoo *et al.* (2002)
-do-	1.16	Andhra Pradesh (India)	Krishnaiah *et al*. (2002)
-do-	2.78	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	1.48	West Godavari (A.P)	-do-
Carbofuran	68	Japan	Yoo *et al.* (2002)
-do-	4.0	Tamil Nadu (India)	Sujatha and Regupathy (2003)
Synthetic pyrethroids			
Ethofenprox	2.04	Andhra Pradesh (India)	Krishnaiah *et al*. (2002)
Chitin synthesis inhibitors			
Buprofezin	1.84	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)

Table 2.1 (Cont.)

Insecticide group & Insecticide	Resistance factor	Country/Area	Reference
Neonicotinoids			
Imidacloprid	2.77	Andhra Pradesh (India)	Krishnaiah *et al*. (2002)
-do-	107-316	China	Wang *et al.* (2008a)
-do-	135.3-301.3	China	Wang *et al.* (2008b)
-do-	24.50	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	17.28	West Godavari (A.P)	-do-
Imidaclothiz	35-41.2	China	Wang *et al.* (2008b)
Thiamethoxam	9.9	-do-	-do-
-do-	10.2	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	6.53	West Godavari (A.P)	-do-
Clothianidin	28.94	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	19.24	West Godavari (A.P)	-do-
Phenyl pyrazoles			
Ethiprole	1.53	East Godavari (A.P)	Jhansilakshmi *et al.* (2010a)
-do-	2.33	West Godavari (A.P)	-do-
-do-	0.64	East Godavari (A.P)	-do-
Other groups			
Cartap hydrochloride	1.75	Andhra Pradesh (India)	Krishnaiah *et al*. (2002)

Table 3.1. Particulars of insecticides tested for determination of insecticide resistance in *N. lugens.*

S. No.	Technical name	Chemical name	Strength of technical grade	Source of supply
1	Endosulfan	(1,4,5,6,7,7-hexachloro-8,9,10-trinorborn-5-en-2,3-ylene bismethylene) sulphite	96.00%	Hyderabad Chemicals Ltd., Hyderabad
2	Monocrotophos	Dimethyl (E) -1- Methyl -2- (methyl carbamoyl) vinyl phosphate	75.00%	-do-
3	Acephate	O,S-dimethyl-acetylphosphoramidothioate	99.00%	-do-
4	Phosphamidon	2-chloro-2-diethylcarbamoyl-1-methyl vinyl dimethyl phosphate	93.00%	-do-
5	Fenobucarb	2-sec-butyl phenyl methyl-carbamate	98.00%	-do-
6	Ethofenprox	2-(4-ethoxyphenyl)-2-methylpropyl 3-phenoxybenzyl ether	99.40%	Dhanuka Agritech Ltd., Hyderabad
7	Imidacloprid	1-(6-chloro-3-pyridylmethyl)-N-nitro imidazolidin-2-ylideneamine	96.50%	-do-
8	Thiamethoxam	3-(2-chloro-thiazol-5-ylmethyl) 5-(methyl-1,3,5) oxadiazinan-4-ylidene-N-nitroamine	99.07%	Syngenta India Ltd., Hyderabad

Table 3.2. Particulars of synergists used in combination with insecticides against resistant population of *N. lugens* of West Godavari district.

S. No.	Common name of the synergist	Chemical name of the synergist	Strength of the synergist	Source of supply
1	PBO	Piperonyl butoxide	99%	Otto Kemika – Biochemika, Post Box 2850, Mumbai – 400 002
2	TPP	Triphenyl phosphate	99%	Otto Kemika – Biochemika, Post Box 2850, Mumbai – 400 002

Table 3.3. Details of the new insecticides tested for the management of resistant population of *N. lugens* of West Godavari district.

S. No.	Common name/ Trade name	Chemical name	Strength of the Formulation	Source of supply
1	Buprofezin	(*Z*)-2-*tert*-butylimino-3-isopropyl-5-phenyl-1,3,5-thiadiazinan-4-one	25 SC	Bayer Crop Science Ltd., Hyderabad
2	Ethiprole	5-Amino-1-[2,6-dichloro-4-(trifluoromethyl) phenyl]-4-(ethylsulfinyl)-1H-pyrazole-3-carbonitrile	10 SC	Bayer Crop Science Ltd., Hyderabad
3	Imidacloprid + Ethiprole	(1-(6-chloro-3-pyridylmethyl)-N-nitro imidazolidin-2-ylideneamine) + (5-Amino-1-[2,6-dichloro-4-(trifluoromethyl) phenyl]-4-(ethylsulfinyl)-1H-pyrazole-3-carbonitrile)	(40+40) - 80 WG	Bayer Crop Science Ltd., Hyderabad
4	Pymetrozine	4, 5-dihydro-6-methyl-4-[(E)-(3-pyridinyl methylene) amino]-1, 2, 4-triazin-3(2H)-one	50 WG	Syngenta India Ltd., Hyderabad

Table 4.1. Toxicity of endosulfan to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.0097 (0.0083-0.0124)*	0.0404 (0.0292-0.0693)	2.0761±0.2963	2.85	Y=9.1739 + 2.0761x
2	East Godavari	0.0343 (0.0274-.0416)	0.1162 (0.0894-0.1822)	2.4203±0.3695	2.10	Y=8.5438 + 2.4203x
3	West Godavari	0.0353 (0.0292-0.0413)	0.1053 (0.0834-0.1551)	2.6988±0.3952	6.08	Y=8.9190 + 2.6988x
4	Karimnagar	0.0205 (0.0172-0.0234)	0.0508 (0.0421-0.0712)	3.2497±0.4857	4.21	Y=10.4860 + 3.2497x
2009-10						
1	Susceptible	0.0107 (0.0094-0.0134)	0.0443 (0.0322-0.0753)	2.0864±0.2840	1.63	Y=9.1046 + 2.0864x
2	East Godavari	0.0324 (0.0264-0.0393)	0.1179 (0.0904-0.1875)	2.2854±0.3431	1.22	Y=8.4032 + 2.2854x
3	West Godavari	0.0339 (0.0282-0.0403)	0.1120 0.0873-0.1704)	2.4717±0.3609	3.66	Y=8.6315 + 2.4717x
4	Karimnagar	0.0214 (0.0182-0.0254)	0.0555 (0.0443-0.0827)	3.1090±0.5010	3.61	Y=10.1854 + 3.1090x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.2. Toxicity of monocrotophos to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.0230 (0.0173-0.0292)	0.0915 (0.0662-0.1641)	2.1425±0.3477	1.81	Y=8.5060 + 2.1425x
2	East Godavari	0.0545 (0.0492-0.0603)	0.0985 (0.0861-0.1242)	4.9827±0.7701	1.07	Y=11.2949 + 4.9827x
3	West Godavari	0.0694 (0.0623-0.0761)	0.1201 (0.1063-0.1471)	5.3805±0.8174	3.00	Y=11.2335 + 5.3805x
4	Karimnagar	0.0540 (0.0472-0.0603)	0.0992 (0.0863-0.1274)	4.8515±0.7883	3.61	Y=11.1491 + 4.8515x
2009-10						
1	Susceptible	0.0216 (0.0184-0.0267)	0.0797 (0.0603-0.1254)	2.2628±0.3061	4.73	Y=8.7672 + 2.2628x
2	East Godavari	0.0539 (0.0484-0.0595)	0.1047 (0.0903-0.1355)	4.4424±0.6551	1.89	Y=10.6340 + 4.4424x
3	West Godavari	0.0654 (0.0604-0.0713)	0.1190 (0.1063-0.1442)	4.9361±0.6455	0.84	Y=10.8435 + 4.9361x
4	Karimnagar	0.0544 (0.0487-0.0603)	0.1047 (0.0903-0.1374)	4.5119±0.6993	3.16	Y=10.7028 + 4.5119x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.3. Toxicity of acephate to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.0228 (0.0182-0.0281)	0.1069 (0.0782-0.1773)	1.9141±0.2582	6.25	Y=8.1401 + 1.9141x
2	East Godavari	0.0554 (0.0502-0.0612)	0.1060 (0.0932-0.1291)	4.5529±0.5893	2.99	Y=10.7179 + 4.5529x
3	West Godavari	0.0640 (0.0593-0.0692)	0.1184 (0.1052-0.1434)	4.8033±0.6049	1.83	Y=10.7318 + 4.8033x
4	Karimnagar	0.0415 (0.0361-0.0462)	0.0951 (0.0821-0.1192)	3.5598±0.4343	0.85	Y=9.9187 + 3.5598x
2009-10						
1	Susceptible	0.0237 (0.0194-0.0295)	0.0980 (0.0744-0.1543)	2.0816±0.2793	3.57	Y=8.3813 + 2.0816x
2	East Godavari	0.0560 (0.0501-0.0622)	0.1165 (0.1001-0.1492)	4.0277±0.5474	1.48	Y=10.0419 + 4.0277x
3	West Godavari	0.0662 (0.0601-0.0723)	0.1256 (0.1102-0.1563)	4.6164±0.6279	0.80	Y=10.4410 + 4.6164x
4	Karimnagar	0.0505 (0.0451-0.0562)	0.0980 (0.0853-0.1245)	4.4604±0.6639	4.92	Y=10.7807 + 4.4604x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.4. Toxicity of phosphamidon to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.0331 (0.0283-0.0385)	0.0784 (0.0652-0.1102)	3.4246±0.5556	5.21	Y=10.0679 + 3.4246x
2	East Godavari	0.0657 (0.0602-0.0711)	0.1057 (0.0953-0.1272)	6.2183±0.9395	0.27	Y=12.3495 + 6.2183x
3	West Godavari	0.0734 (0.0683-0.0782)	0.1095 (0.1003-0.1264)	7.3795±1.0803	0.22	Y=13.3691 + 7.3795x
4	Karimnagar	0.0641 (0.0592-0.0692)	0.1184 (0.1051-0.1434)	4.8033±0.6049	1.83	Y=10.7318 + 4.8033x
2009-10						
1	Susceptible	0.0313 (0.0262-0.0374)	0.1009 (0.0774-0.1567)	2.5445±0.3824	6.14	Y=8.8251 + 2.5445x
2	East Godavari	0.0639 (0.0584-0.0697)	0.1103 (0.0985-0.1354)	5.4034±0.7746	1.66	Y=11.4542 + 5.4034x
3	West Godavari	0.0722 (0.0673-0.0774)	0.1121 (0.1022-0.1303)	6.7125±0.9352	0.75	Y=12.6600 + 6.7125x
4	Karimnagar	0.0665 (0.0592-0.0793)	0.1227 (0.1082-0.1522)	4.7066±0.6551	1.52	Y=10.5699 + 4.7066x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.5. Toxicity of fenobucarb to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.0054 (0.0052-0.0062)	0.0109 (0.0092-0.0153)	4.2859±0.7056	3.04	Y=14.6847 + 4.2859x
2	East Godavari	0.0076 (0.0073-0.0083)	0.0122 (0.0114-0.0151)	6.3690±0.9946	0.50	Y=18.4641 + 6.3690x
3	West Godavari	0.0075 (0.0072-0.0081)	0.0115 (0.0103-0.0142)	6.8764±0.9979	1.41	Y=19.6033 + 6.8764x
4	Karimnagar	0.0069 (0.0062-0.0071)	0.0116 (0.0101-0.0142)	5.3120±0.7052	2.02	Y=16.5485 + 5.3120x
2009-10						
1	Susceptible	0.0052 (0.0048-0.0062)	0.0105 (0.0093-0.0144)	4.2077±0.6489	4.99	Y=14.6022 + 4.2077x
2	East Godavari	0.0075 (0.0073-0.0084)	0.0132 (0.0124-0.0173)	5.2335±0.7746	0.35	Y=16.1012 + 5.2335x
3	West Godavari	0.0088 (0.0082-0.0104)	0.0158 (0.0143-0.0205)	5.0434±0.6951	4.82	Y=15.3541 + 5.0434x
4	Karimnagar	0.0069 (0.0063-0.0082)	0.0136 (0.0124-0.0187)	4.3780±0.6267	1.81	Y=14.4508 + 4.3780x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.6. Toxicity of ethofenprox to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.0030 (0.0023-0.0051)	0.0097 (0.0082-0.0143)	2.5127±0.3249	4.71	Y=11.3449 + 2.5127x
2	East Godavari	0.0042 (0.0032-0.0053)	0.0123 (0.0101-0.0182)	2.7070±0.4109	1.92	Y=11.4463 + 2.7070x
3	West Godavari	0.0045 (0.0035-0.0053)	0.0119 (0.0101-0.0117)	3.0375±0.4879	3.43	Y=12.1313 + 3.0375x
4	Karimnagar	0.0033 (0.0024-0.0042)	0.0098 (0.0082-0.0154)	2.7332±0.4240	5.23	Y=11.7709 + 2.7332x
2009-10						
1	Susceptible	0.0033 (0.0027-0.0042)	0.0108 (0.0084-0.0172)	2.4798±0.3598	4.93	Y=11.1581 + 2.4798x
2	East Godavari	0.0038 (0.0027-0.0043)	0.0111 (0.0092-0.0153)	2.7713±0.3714	3.43	Y=11.6932 + 2.7713x
3	West Godavari	0.0045 (0.0041-0.0053)	0.0120 (0.0105-0.0184)	2.9541±0.4710	6.75	Y=11.9474 + 2.9541x
4	Karimnagar	0.0034 (0.0031-0.0042)	0.0091 (0.0071-0.0141)	3.0102±0.4774	4.80	Y=12.4196 + 3.0102x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.7. Toxicity of imidacloprid to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.00024 (0.00019-0.00032)	0.0060 (0.0053-0.0071)	0.9141±0.0132	1.93	Y=8.3076 + 0.9141x
2	East Godavari	0.0069 (0.0061-0.0093)	0.0375 (0.0264-0.0703)	1.7524±0.2349	2.75	Y=8.7803 + 1.7524x
3	West Godavari	0.0112 (0.0083-0.0132)	0.0564 (0.0353-0.0925)	1.8300±0.2527	0.39	Y=8.6559 + 1.8300x
4	Karimnagar	0.0088 (0.0073-0.0112)	0.0483 (0.0334-0.0863)	1.7322±0.2190	0.33	Y=8.5599 + 1.7322x
2009-10						
1	Susceptible	0.00021 (0.00018-0.00051)	0.0039 (0.0031-0.0052)	1.0021±0.0147	2.18	Y=8.6857 + 1.0021x
2	East Godavari	0.0073 (0.0064-0.0093)	0.0327 (0.0234-0.0565)	1.9837±0.2612	1.50	Y=9.2280 + 1.9837x
3	West Godavari	0.0099 (0.0084-0.0124)	0.0572 (0.0382-0.1084)	1.6817±0.2161	0.14	Y=8.3702 + 1.6817x
4	Karimnagar	0.0088 (0.0073-0.0114)	0.0522 (0.0354-0.0983)	1.6656±0.2210	2.02	Y=8.4169 + 1.6656x

FL= Fiducial Limits
*Figures in parenthesis are Fiducial Limits.

Table 4.8. Toxicity of thiamethoxam to *N. lugens* from different locations of Andhra Pradesh.

S. No.	Location	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Susceptible	0.00074 (0.0002-0.0009)	0.0082 (0.0041-0.0097)	1.2224±0.0237	0.96	Y=8.8363 + 1.2244x
2	East Godavari	0.0063 (0.0023-0.0082)	0.0306 (0.0214-0.0617)	1.8706±0.3033	2.07	Y=9.1125 + 1.8706x
3	West Godavari	0.0097 0.0053-0.0115)	0.0233 (0.0193-0.0354)	3.3958±0.5165	7.28	Y=11.8243 + 3.3958x
4	Karimnagar	0.0094 (0.0083-0.0115)	0.0222 (0.0181-0.0332)	3.4473±0.5132	6.11	Y=11.9792 + 3.4473x
2009-10						
1	Susceptible	0.00078 (0.00052-0.00083)	0.00946 (0.00742-0.0182)	1.1822±0.0232	1.04	Y=8.6741 + 1.1822x
2	East Godavari	0.0061 (0.0052-0.00852)	0.0383 (0.0243-0.0863)	1.6153±0.2585	2.83	Y=8.5696 + 1.6153x
3	West Godavari	0.0101 (0.0093-0.0122)	0.0238 (0.0192-0.0351)	3.4725±0.5172	9.28	Y=11.9158 + 3.4725x
4	Karimnagar	0.0089 (0.0082-0.0103)	0.0187 (0.0163-0.0252)	3.9719±0.5583	5.87	Y=13.1409 + 3.9719x

FL= Fiducial Limit
*Figures in parenthesis are Fiducial Limits

Table 4.9. Relative degree of resistance among the *N. lugens* populations of three districts to endosulfan.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with	
		SUS	KNR	EG		SUS	KNR	EG	Recommended concentration (0.07 %)	
									LC_{50} (%)	LC_{90} (%)
2008-09										
W. Godavari	0.0353	3.63	1.72	1.02	0.1053	2.60	2.07	--	0.50	1.50
E. Godavari	0.0343	3.53	1.67	--	0.1162	2.87	2.28	--	0.49	1.66
Karimnagar	0.0205	2.11	--	--	0.0508	1.26	--	--	0.29	0.72
Susceptible	0.0097	--	--	--	0.0404	--	--	--	--	--
2009-10										
W. Godavari	0.0339	3.16	1.58	1.04	0.1120	2.52	2.01	--	0.48	1.60
E. Godavari	0.0324	3.02	1.51	--	0.1179	2.66	2.12	--	0.46	1.68
Karimnagar	0.0214	2.00	--	--	0.0555	1.25	--	--	0.30	0.79
Susceptible	0.0107	--	--	--	0.0443	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF = Resistance Factor

Table 4.10. Relative degree of resistance among the *N. lugens* populations of three districts to monocrotophos.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with		
		SUS	KNR	EG		SUS	KNR	EG	Base line data*	Recommended concentration (0.0792 %)	
									LC_{50} (%)	LC_{50} (%)	LC_{90} (%)
2008-09											
W. Godavari	0.0694	3.01	1.29	1.27	0.1201	1.31	1.21	1.22	4.75	0.88	1.51
E. Godavari	0.0545	2.37	--	--	0.0985	1.07	--	--	4.02	0.69	1.24
Karimnagar	0.0540	2.34	--	--	0.0992	1.08	--	--	--	0.68	1.25
Susceptible	0.0230	--	--	--	0.0915	--	--	--	--	--	--
2009-10											
W. Godavari	0.0654	3.07	1.20	1.21	0.1190	1.49	1.13	1.13	4.48	0.82	1.50
E. Godavari	0.0539	2.50	--	--	0.1047	1.31	--	--	3.98	0.68	1.32
Karimnagar	0.0544	2.52	--	--	0.1047	1.31	1.31	--	--	0.68	1.32
Susceptible	0.0216	--	--	--	0.0797	--	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar . RF=Resistance Factor. SUS – Susceptible.
* (LC_{50} (E.G) = 135.30 ppm (0.01353%); LC_{50} (W.G) = 146.60 ppm (0.0146%); Jhansilakshmi *et al.*, 2010a).

Table 4.11. Relative degree of resistance among the *N. lugens* populations of three districts to acephate.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with		
		SUS	KNR	EG		SUS	KNR	EG	Base line data*	Recommended concentration (0.1 %)	
									LC_{50} (%)	LC_{50} (%)	LC_{90} (%)
2008-09											
W. Godavari	0.0640	2.80	1.54	1.15	0.1184	1.10	1.24	1.11	12.0	0.64	1.18
E. Godavari	0.0554	2.42	1.33	--	0.1060	--	1.11	--	9.89	0.55	1.06
Karimnagar	0.0415	--	--	--	0.0951	--	--	--	--	0.41	0.95
Susceptible	0.0228	--	--	--	0.1069	--	--	--	--	--	--
2009-10											
W. Godavari	0.0662	2.79	1.31	1.18	0.1256	1.28	1.28	1.08	12.49	0.66	1.26
E. Godavari	0.0560	2.36	1.10	--	0.1165	1.19	1.19	--	10.00	0.56	1.17
Karimnagar	0.0505	1.31	--	--	0.0980	--	--	--	--	0.50	0.98
Susceptible	0.0237	--	--	--	0.0980	--	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF=Resistance Factor.

* (LC_{50} (E.G) = 56.93 ppm (0.0056%); LC_{50} (W.G) = 53.65 ppm (0.0053%); Jhansilakshmi *et al.*, 2010a).

Table 4.12. Relative degree of resistance among the *N. lugens* populations of three districts to phosphamidon.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with		
		SUS	KNR	EG		SUS	KNR	EG	Base line data*	Recommended concentration (0.08 %)	
									LC_{50} (%)	LC_{50} (%)	LC_{90} (%)
2008-09											
W. Godavari	0.0734	2.22	1.14	1.12	0.1095	1.40	--	1.04	17.06	0.92	1.37
E. Godavari	0.0657	1.98	1.02	--	0.1057	1.35	--	--	--	0.82	1.32
Karimnagar	0.0641	1.93	--	--	0.1184	1.51	--	1.12	--	0.80	1.48
Susceptible	0.0331	--	--	--	0.0784	--	--	--	--	--	--
2009-10											
W. Godavari	0.0722	2.30	1.09	1.12	0.1121	1.40	--	1.01	16.79	0.90	1.40
E. Godavari	0.0639	2.04	--	--	0.1103	1.38	--	--	--	0.79	1.38
Karimnagar	0.0665	2.12	--	1.04	0.1227	1.53	--	1.11	--	0.83	1.53
Susceptible	0.0313	--	--	--	0.1009	--	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF=Resistance Factor.

* (LC_{50} (W.G) = 43 ppm (0.0043%); Sarupa *et al*., 1998).

Table 4.13. Relative degree of resistance among the *N. lugens* populations of three districts to fenobucarb.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with		
		SUS	KNR	EG		SUS	KNR	EG	Base line data*	Recommended concentration (0.1%)	
									LC_{50} (%)	LC_{50} (%)	LC_{90} (%)
2008-09											
W. Godavari	0.0075	1.39	1.09	--	0.0115	1.06	--	--	1.74	0.075	0.11
E. Godavari	0.0076	1.41	1.10	--	0.0122	1.12	1.05	--	0.93	0.076	0.12
Karimnagar	0.0069	1.28	--	--	0.0116	1.06	--	--	--	0.069	0.12
Susceptible	0.0054	--	--	--	0.0109	--	--	--	--	--	--
2009-10											
W. Godavari	0.0088	1.69	1.28	1.17	0.0158	1.50	1.16	1.20	2.04	0.088	0.158
E. Godavari	0.0075	1.44	1.09	--	0.0132	1.26	--	--	0.92	0.075	0.132
Karimnagar	0.0069	1.33	--	--	0.0136	1.30	--	1.03	--	0.069	0.136
Susceptible	0.0052	--	--	--	0.0105	--	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF=Resistance Factor.

* (LC_{50} (E.G) = 81.39 ppm (0.0081%); LC_{50} (W.G) = 43.47 ppm (0.0043%); Jhansilakshmi *et al.*, 2010a

Table 4.14. Relative degree of resistance among the *N. lugens* populations of three districts to ethofenprox.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with	
		SUS	KNR	EG		SUS	KNR	EG	Recommended concentration (0.015 %)	
									LC_{50} (%)	LC_{90} (%)
2008-09										
W. Godavari	0.0045	1.50	1.36	1.07	0.0119	1.23	1.21	--	0.3	0.79
E. Godavari	0.0042	1.40	1.27	--	0.0123	1.27	1.26	--	0.28	0.82
Karimnagar	0.0033	1.10	--	--	0.0098	1.01	--	--	0.22	0.65
Susceptible	0.0030	--	--	--	0.0097	--	--	--	--	--
2009-10										
W. Godavari	0.0045	1.36	1.32	1.18	0.0120	1.11	1.31	--	0.30	0.80
E. Godavari	0.0038	1.15	1.12	--	0.0111	1.02	1.22	--	0.25	0.74
Karimnagar	0.0034	1.03	--	--	0.0091	--	--	--	0.23	0.60
Susceptible	0.0033	--	--	--	0.0108	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF=Resistance Factor.

Table 4.15. Relative degree of resistance among the *N. lugens* populations of three districts to imidacloprid.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with			
		SUS	KNR	EG		SUS	KNR	EG	Base line data*		Recommended concentration (0.0045 %)	
									LC_{50} (%) 2004*	LC_{50} (%) 2006**	LC_{50} (%)	LC_{90} (%)
2008-09												
W. Godavari	0.0112	46.66	1.27	1.62	0.0564	9.40	1.16	1.50	--	2.639	2.49	12.53
E. Godavari	0.0069	28.75	--	--	0.0375	6.25	--	--	4.79	1.17	1.53	8.33
Karimnagar	0.0088	36.66	--	1.27	0.0483	8.05	--	1.29	--	--	1.96	10.73
Susceptible	0.00024	--	--	--	0.0060	--	--	--	--	--	--	--
2009-10												
W. Godavari	0.0099	47.14	1.13	1.36	0.0572	14.66	1.09	1.75	--	2.38	2.20	12.71
E. Godavari	0.0073	34.76	--	--	0.0327	8.38	8.38	--	5.07	1.23	1.62	7.26
Karimnagar	0.0088	41.90	--	1.20	0.0522	13.38	--	1.60	--	--	1.95	11.60
Susceptible	0.00021	--	--	--	0.0039	--	--	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF=Resistance Factor

*2004 - LC_{50} (E.G) = 14.44 ppm (0.00144%) (Jhansilakshmi *et al.,* 2010a)

**2006 - LC_{50} (E.G) = 59.06 ppm (0.0059%); LC_{50} (W.G) = 41.67 ppm (0.004167%); (Jhansilakshmi *et al.,* 2010a).

Table 4.16. Relative degree of resistance among the *N. lugens* populations of three districts to thiamethoxam.

District	LC_{50} (%)	RF at LC_{50} in comparison with the *N. lugens* population of			LC_{90} (%)	RF at LC_{90} in comparison with the *N. lugens* population of			RF in comparison with			
		SUS	KNR	EG		SUS	KNR	EG	Base line data*		Recommended concentration (0.005 %)	
									LC_{50} (%) 2004*	LC_{50} (%) 2006*	LC_{50} (%)	LC_{90} (%)
2008-09												
W. Godavari	0.0097	13.11	1.03	1.54	0.0233	2.84	1.05	--	--	6.18	1.94	4.66
E. Godavari	0.0063	8.51	--	--	0.0306	3.73	1.38	--	15.82	2.62	1.26	6.12
Karimnagar	0.0094	12.70	--	1.49	0.0222	2.70	--	--	--	--	1.88	4.44
Susceptible	0.00074	--	--	--	0.0082	--	--	--	--	--	--	--
2009-10												
W. Godavari	0.0101	12.94	1.13	1.66	0.0238	2.51	1.27	--	--	6.43	2.02	4.76
E. Godavari	0.0061	7.82	--	--	0.0383	4.05	2.04	--	15.32	2.54	1.22	7.66
Karimnagar	0.0089	11.41	--	1.46	0.0187	1.98	--	--	--	--	1.78	3.74
Susceptible	0.00078	--	--	--	0.00946	--	--	--	--	--	--	--

EG – East Godavari. WG – West Godavari. KNR – Karimnagar. SUS – Susceptible. RF=Resistance Factor

*2004 - LC_{50} (E.G) = 3.98 ppm (0.000398%) (Jhansilakshmi *et al.,* 2010a)

**2006 - LC_{50} (E.G) = 24.57 ppm (0.0024%); LC_{50} (W.G) = 15.74 ppm (0.00157%); (Jhansilakshmi *et al.,* 2010a).

Table 4.17. Toxicity of Piperonyl butoxide (PBO) with test insecticides to the resistant population of *N. lugens* (2008-09).

S. No.	Treatment	LC_{50} (%) (95% FL)	LC_{90} (%) (95% FL)	Slope ± S.E (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
1	Endosulfan + PBO	0.0035 (0.0028 - 0.0042)*	0.0109 (0.0092 - 0.0153)	2.5896 ± 0.0856	2.16	Y=11.3547 + 2.5896 x
2	Monocrotophos + PBO	0.0035 (0.0028 - 0.0042)	0.0105 (0.0092 - 0.0142)	2.6738 ± 0.0975	2.67	Y=11.5628 + 2.6738 x
3	Acephate + PBO	0.0034 (0.0022 - 0.0045)	0.0088 (0.0072 - 0.0114)	3.1452 ± 0.1194	1.42	Y=12.7497 + 3.1452 x
4	Phosphamidon + PBO	0.0046 (0.0043 - 0.0057)	0.0095 (0.0081 - 0.0123)	4.1078 ± 0.5659	5.25	Y=14.5800 + 4.1078 x
5	Fenobucarb + PBO	0.0031 (0.0021 - 0.0043)	0.0074 (0.0062 - 0.0093)	3.4832 ± 0.4922	5.21	Y=13.6993 + 3.4832 x
6	Ethofenprox + PBO	0.0012 (0.0007 - 0.0024)	0.0087 (0.0061 - 0.0194)	1.5048 ± 0.2668	1.84	Y=9.3848 + 1.5048 x
7	Imidacloprid + PBO	0.0035 (0.0026 - 0.0042)	0.0091 (0.0083 - 0.0124)	3.0926 ± 0.1523	2.71	Y=12.5842 + 3.0926 x
8	Thiamethoxam + PBO	0.0028 (0.0012 - 0.0044)	0.0118 (0.0092 - 0.0193)	2.0385 ± 0.0644	3.75	Y=10.2107 + 2.0385 x

FL = Fiducial Limits. *Figures in parenthesis are Fiducial Limits.

Table 4.18. Synergistic effect of Piperonyl butoxide (PBO) in combination with test insecticides to *N. lugens* population of West Godavari District (2008-09).

S. No.	Insecticide	LC_{50}	LC_{90}	Synergistic ratio	
				LC_{50}	LC_{90}
1	**Endosulfan**	**0.0353**	**0.1053**	--	--
	Endosulfan + PBO	0.0035	0.0109	10.08	9.66
2	**Monocrotophos**	**0.0694**	**0.1201**	--	--
	Monocrotophos + PBO	0.0035	0.0105	19.83	11.43
3	**Acephate**	**0.0640**	**0.1184**	--	--
	Acephate + PBO	0.0034	0.0088	18.82	13.45
4	**Phosphamidon**	**0.0734**	**0.1095**	--	--
	Phosphamidon + PBO	0.0046	0.0095	15.95	11.52
5	**Fenobucarb**	**0.0075**	**0.0115**	--	--
	Fenobucarb + PBO	0.0031	0.0074	2.41	1.55
6	**Ethofenprox**	**0.0045**	**0.0119**	--	--
	Ethofenprox + PBO	0.0012	0.0087	3.75	1.37
7	**Imidacloprid**	**0.0112**	**0.0564**	--	--
	Imidacloprid + PBO	0.0035	0.0091	3.2	6.19
8	**Thiamethoxam**	**0.0097**	**0.0233**	--	--
	Thiamethoxam + PBO	0.0028	0.0118	3.46	1.97

Table 4.19. Toxicity of Piperonyl butoxide (PBO) with test insecticides against the resistant population of *N. lugens* (2009-10).

S. No.	Treatment	LC_{50} (%) (95% FL)	LC_{90} (%) (95% FL)	Slope ± S.E (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
1	Endosulfan + PBO	0.0040 (0.0031 - 0.0052)	0.0098 (0.008 - 0.0134)	3.3750 ± 0.4779	5.03	Y=13.0651 + 3.3750 x
2	Monocrotophos + PBO	0.0033 (0.0028 - 0.0042)	0.0109 (0.0092 - 0.0153)	2.4833 ± 0.3191	2.18	Y=11.1588 + 2.4833 x
3	Acephate + PBO	0.0031 (0.0024 - 0.0043)	0.0073 (0.0071 - 0.0094)	3.4419 ± 0.4266	4.59	Y=13.6311 + 3.4419 x
4	Phosphamidon + PBO	0.0046 (0.0043 - 0.0053)	0.0113 (0.0092 - 0.0167)	3.2763 ± 0.4662	4.93	Y=12.6494 + 3.2763 x
5	Fenobucarb + PBO	0.0036 (0.0030 - 0.0042)	0.0091 (0.0082 - 0.0132)	3.1995 ± 0.4751	1.16	Y=12.8013 + 3.1995 x
6	Ethofenprox + PBO	0.0014 (0.0009 - 0.0023)	0.0064 (0.0052 - 0.0103)	1.9329 ± 0.2782	2.15	Y=10.5157 + 1.9329 x
7	Imidacloprid + PBO	0.0037 (0.0028 - 0.0043)	0.0097 (0.0082 - 0.0132)	3.0860 ± 0.4175	3.05	Y=12.4882 + 3.0860 x
8	Thiamethoxam + PBO	0.0029 (0.0014 - 0.0047)	0.0120 (0.0094 - 0.0205)	2.1094 ± 0.2969	2.10	Y=10.3306 + 2.1094 x

FL= Fiducial Limits. *Figures in parenthesis are Fiducial Limits.

Table 4.20. Synergistic effect of Piperonyl butoxide (PBO) in combination with test insecticides to *N. lugens* population of West Godavari district (2009-10).

S. No.	Insecticide	LC_{50}	LC_{90}	Synergistic ratio	
				LC_{50}	LC_{90}
1	**Endosulfan**	**0.0339**	**0.1120**	--	--
	Endosulfan + PBO	0.0040	0.0098	8.48	11.42
2	**Monocrotophos**	**0.0654**	**0.1190**	--	--
	Monocrotophos + PBO	0.0033	0.0109	19.81	10.91
3	**Acephate**	**0.0662**	**0.1256**	--	--
	Acephate + PBO	0.0031	0.0073	21.35	17.20
4	**Phosphamidon**	**0.0722**	**0.1121**	--	--
	Phosphamidon + PBO	0.0046	0.0113	15.69	9.92
5	**Fenobucarb**	**0.0088**	**0.0158**	--	--
	Fenobucarb + PBO	0.0036	0.0091	2.44	1.73
6	**Ethofenprox**	**0.0045**	**0.0120**	--	--
	Ethofenprox + PBO	0.0014	0.0064	3.21	1.88
7	**Imidacloprid**	**0.0099**	**0.0572**	--	--
	Imidacloprid + PBO	0.0037	0.0097	2.67	5.89
8	**Thiamethoxam**	**0.0101**	**0.0238**	--	--
	Thiamethoxam + PBO	0.0029	0.0120	3.48	1.98

. **Table 4.21. Toxicity of Triphenyl phosphate (TPP) with test insecticides to the resistant population of *N. lugens* (2008-09).**

S. No.	Treatment	LC_{50} (%) (95% FL)	LC_{90} (%) (95% FL)	Slope ± S.E (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
1	Endosulfan + TPP	0.0053 (0.0041 - 0.0062)	0.0142 (0.0112 - 0.0213)	3.0121 ± 0.1610	3.74	Y=11.8476 + 3.0121 x
2	Monocrotophos + TPP	0.0043 (0.0032 - 0.0052)	0.0113 (0.0091 - 0.0152)	3.0868 ± 0.1464	5.92	Y=12.2876 + 3.0868 x
3	Acephate + TPP	0.0045 (0.0032 - 0.0056)	0.0102 (0.0092 - 0.0134)	3.6650 ± 0.1937	2.51	Y=13.5817 + 3.6650 x
4	Phosphamidon + TPP	0.0569 (0.0522 - 0.0624)	0.0959 (0.0852 - 0.1184)	5.6605 ± 0.8713	1.74	Y=12.0439 + 5.6605 x
5	Fenobucarb + TPP	0.0047 (0.0039 - 0.0053)	0.0086 (0.0092 - 0.0104)	4.8773 ± 0.6450	1.25	Y=16.3622 + 4.8773 x
6	Ethofenprox + TPP	0.0025 (0.0018 - 0.0034)	0.0072 (0.0063 - 0.0103)	2.7310 ± 0.3334	6.31	Y=12.1260 + 2.7310 x
7	Imidacloprid + TPP	0.0102 (0.0082 - 0.0132)	0.0502 (0.0351 - 0.0892)	1.8513 ± 0.0540	1.48	Y=8.6862 + 1.8513 x
8	Thiamethoxam + TPP	0.0094 (0.0083 - 0.0112)	0.0223 (0.0182 - 0.0334)	3.4092 ± 0.5114	5.711	Y=11.9093 + 3.4092 x

FL= Fiducial Limits. *Figures in parenthesis are Fiducial Limits.

Table 4.22. Synergistic effect of Triphenyl phosphate (TPP) in combination with test insecticides to *N. lugens* population of West Godavari district (2008-09).

S. No.	Insecticide	LC_{50}	LC_{90}	Synergistic ratio	
				LC_{50}	LC_{90}
1	**Endosulfan**	**0.0353**	**0.1053**	--	--
	Endosulfan + TPP	0.0053	0.0142	6.66	7.41
2	**Monocrotophos**	**0.0694**	**0.1201**	--	--
	Monocrotophos + TPP	0.0043	0.0113	16.13	10.62
3	**Acephate**	**0.0640**	**0.1184**	--	--
	Acephate + TPP	0.0045	0.0102	14.22	11.60
4	**Phosphamidon**	**0.0734**	**0.1095**	--	--
	Phosphamidon + TPP	0.0569	0.0959	1.28	1.14
5	**Fenobucarb**	**0.0075**	**0.0115**	--	--
	Fenobucarb + TPP	0.0047	0.0086	1.59	1.33
6	**Ethofenprox**	**0.0045**	**0.0119**	--	--
	Ethofenprox + TPP	0.0025	0.0072	1.8	1.65
7	**Imidacloprid**	**0.0112**	**0.0564**	--	--
	Imidacloprid + TPP	0.0102	0.0502	1.09	1.12
8	**Thiamethoxam**	**0.0097**	**0.0233**	--	--
	Thiamethoxam + TPP	0.0094	0.0223	1.03	1.03

Table 4.23. Toxicity of Triphenyl phosphate (TPP) with test insecticides to the resistant population of *N. lugens* (2009-10).

S. No.	Treatment	LC_{50} (%) (95% FL)	LC_{90} (%) (95% FL)	Slope ± S.E (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
1	Endosulfan + TPP	0.0055 (0.0043 - 0.0062)	0.0130 (0.0102 - 0.0203)	3.4482 ± 0.5674	3.53	Y=12.7790 + 3.4482 x
2	Monocrotophos + TPP	0.0046 (0.0042 - 0.0056)	0.0122 (0.0102 - 0.0183)	3.0515 ± 0.4623	3.12	Y=12.1196 + 3.0515 x
3	Acephate + TPP	0.0053 (0.0048 - 0.0062)	0.0097 (0.0092 - 0.0123)	4.9857 ± 0.7240	1.61	Y=16.3185 + 4.9857 x
4	Phosphamidon + TPP	0.0559 (0.0512 - 0.0602)	0.0917 (0.0821 - 0.1112)	5.9649 ± 0.8991	5.54	Y=12.4682 + 5.9649 x
5	Fenobucarb + TPP	0.0051 (0.0042 - 0.0063)	0.0104 (0.0093 - 0.0137)	4.1615 ± 0.5847	2.27	Y=14.5281 + 4.1615 x
6	Ethofenprox + TPP	0.0023 (0.0017 - 0.00345)	0.0089 (0.0072 - 0.0137)	2.2337 ± 0.2422	6.87	Y=10.8621 + 2.2337 x
7	Imidacloprid + TPP	0.0091 (0.0072 - 0.0113)	0.0471 (0.0332 - 0.0821)	1.7943 ± 0.2218	0.297	Y=8.6612 + 1.7943 x
8	Thiamethoxam + TPP	0.0081 (0.0072 - 0.0091)	0.0200 (0.0161 - 0.0304)	3.2778 ± 0.5148	4.193	Y=11.8439 + 3.2778 x

FL= Fiducial Limits. *Figures in parenthesis are Fiducial Limits.

Table 4.24. Synergistic effect of Triphenyl phosphate (TPP) in combination with test insecticides to *N. lugens* population of West Godavari district (2009-10).

S. No.	Insecticide	LC_{50}	LC_{90}	Synergistic ratio	
				LC_{50}	LC_{90}
1	**Endosulfan**	**0.0339**	**0.1120**	--	--
	Endosulfan + TPP	0.0055	0.0130	6.16	8.61
2	**Monocrotophos**	**0.0654**	**0.1190**	--	--
	Monocrotophos + TPP	0.0046	0.0122	14.2	9.75
3	**Acephate**	**0.0662**	**0.1256**	--	--
	Acephate + TPP	0.0053	0.0097	12.49	12.94
4	**Phosphamidon**	**0.0722**	**0.1121**	--	--
	Phosphamidon + TPP	0.0559	0.0917	1.29	1.22
5	**Fenobucarb**	**0.0088**	**0.0158**	--	--
	Fenobucarb + TPP	0.0051	0.0104	1.72	1.51
6	**Ethofenprox**	**0.0045**	**0.0120**	--	--
	Ethofenprox + TPP	0.0023	0.0089	1.95	1.34
7	**Imidacloprid**	**0.0099**	**0.0572**	--	--
	Imidacloprid + TPP	0.0091	0.0471	1.08	1.21
8	**Thiamethoxam**	**0.0101**	**0.0238**	--	--
	Thiamethoxam + TPP	0.0081	0.0200	1.24	1.19

Table 4.25. Toxicity of selected new insecticides to *N. lugens* population of West Godavari district.

S. No.	Insecticide	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope ± S.E. (b)	Heterogeneity (χ^2)	Regression equation Y = a + bx
2008-09						
1	Buprofezin 25 SC	0.00014 (0.00009 - 0.00037)	0.00091 (0.0002 - 0.0012)	1.5850 ± 0.0470	3.58	Y = 11.099 + 1.5850x
2	Imidacloprid + Ethiprole (40 + 40) - 80 WG	0.00018 (0.000095 - 0.00024)	0.001816 (0.0008 - 0.0027)	2.2742 ± 0.0250	4.53	Y = 09.7740 + 1.2742x
3	Ethiprole 10 SC	0.00035 (0.00023 - 0.00048)	0.0015 (0.0008 - 0.0024)	1.9994 ± 0.0650	1.76	Y = 11.9080 + 1.9994x
4	Pymetrozine 50 WG	0.00018 (0.00009 - 0.00032)	0.0015 (0.00092 - 0.0027)	1.4014 ± 0.0264	5.66	Y = 10.2387 + 1.4014x
2009-10						
1	Buprofezin 25 SC	0.00015 (0.000093 - 0.00032)	0.00070 (0.00023 - 0.00093)	1.9117 ± 0.0535	5.47	Y = 12.3023 + 1.9117x
2	Imidacloprid + Ethiprole (40 + 40) - 80 WG	0.00020 (0.000017- 0.00032)	0.0015 (0.0011 - 0.0021)	1.4520 ± 0.0296	2.20	Y = 10.3663 + 1.4520x
3	Ethiprole 10 SC	0.00035 (0.00021 - 0.00042)	0.0017 (0.00097 - 0.0023)	1.8680 ± 0.0587	3.12	Y = 11.4538 + 1.8680x
4	Pymetrozine 50 WG	0.00019 (0.00008 - 0.00025)	0.0015 (0.00096 - 0.0021)	1.4270 ± 0.0279	5.74	Y = 10.383 + 1.4270x

FL= Fiducial Limits. *Figures in parenthesis are Fiducial Limits. S. E. Standard Error.

Table 4.26. Relative toxicity of new insecticides against relatively resistant *N. lugens* population of West Godavari district.

S. No.	Insecticide	Number of folds toxic in comparison with			
		Ethiprole	Pymetrozine	Imidacloprid + Ethiprole	Buprofezin
2008-09					
1	Buprofezin				
	LC_{50} – 0.00014%	*2.5	1.28	1.29	--
	LC_{90} – 0.00091%	**1.64	1.64	1.99	--
2	Imidacloprid + Ethiprole				
	LC_{50} – 0.00018%	1.94	0.10	--	0.77
	LC_{90} – 0.001816%	0.82	0.04	--	0.50
3	Pymetrozine				
	LC_{50} – 0.00018%	1.94	--	1.00	0.77
	LC_{90} - 0.0015%	1.00	--	1.21	0.60
4	Ethiprole				
	LC_{50} – 0.00035%	--	0.51	0.51	0.40
	LC_{90} – 0.0015%	--	1.00	1.21	0.60
2009-10					
1	Buprofezin				
	LC_{50} – 0.00015%	2.33	1.26	1.33	--
	LC_{90} – 0.00070%	2.42	2.14	2.14	--
2	Imidacloprid + Ethiprole				
	LC_{50} – 0.00020%	1.75	0.95	--	0.75
	LC_{90} – 0.0015%	1.13	1.00	--	0.46
3	Pymetrozine				
	LC_{50} – 0.00019%	1.84	--	1.05	0.79
	LC_{90} – 0.0015%	1.13	--	1.00	0.47
4	Ethiprole				
	LC_{50} – 0.00035%	--	0.54	0.57	0.42
	LC_{90} – 0.0017%	--	0.88	0.88	0.41

* Number of folds toxic at LC_{50} level. ** Number of folds toxic at LC_{90} level.

Table 4.27. Relative toxicity of novel insecticides in comparison with test insecticides against relatively resistant *N. lugens* Population of West Godavari district (2008-09).

S. No.	Conventional insecticides	LC level (%)	Toxicity index / Relative toxicity of new insecticides over conventional insecticides			
			Ethiprole	Pymetrozine	Imidacloprid + Ethiprole	Buprofezin
1	Endosulfan	LC_{50}	100.86	196.11	196.11	252.14
		LC_{90}	70.20	70.20	57.98	115.71
2	Monocrotophos	LC_{50}	198.29	385.56	385.56	495.71
		LC_{90}	80.07	80.07	66.13	131.98
3	Acephate	LC_{50}	182.86	355.56	355.56	457.14
		LC_{90}	78.93	78.93	65.20	130.11
4	Phosphamidon	LC_{50}	209.71	407.78	407.78	524.29
		LC_{90}	73.00	73.00	60.30	120.33
5	Fenobucarb	LC_{50}	21.43	41.67	41.67	53.57
		LC_{90}	7.67	7.67	6.33	12.64
6	Ethofenprox	LC_{50}	12.86	25.00	25.00	32.14
		LC_{90}	7.93	7.93	6.55	13.08
7	Imidacloprid	LC_{50}	32.00	62.22	62.22	80.00
		LC_{90}	37.60	37.60	31.06	61.98
8	Thiamethoxam	LC_{50}	27.71	53.89	53.89	69.29
		LC_{90}	15.53	15.53	12.83	25.60

Table 4.28. Relative toxicity of novel insecticides in comparison with test insecticides against relatively resistant *N .lugens* population of West Godavari district (2009-10).

S. No.	Conventional insecticides	LC level (%)	Toxicity index / Relative toxicity of new insecticides over conventional insecticides			
			Ethiprole	Pymetrozine	Imidacloprid + Ethiprole	Buprofezin
1	Endosulfan	LC_{50}	96.86	178.42	169.50	226.00
		LC_{90}	65.88	74.67	74.67	160.00
2	Monocrotophos	LC_{50}	186.86	344.21	327.00	436.00
		LC_{90}	70.00	79.33	79.33	170.00
3	Acephate	LC_{50}	189.14	348.42	331.00	441.33
		LC_{90}	73.88	83.73	83.73	179.43
4	Phosphamidon	LC_{50}	206.29	380.00	361.00	481.33
		LC_{90}	65.94	74.73	74.73	160.14
5	Fenobucarb	LC_{50}	25.14	46.32	44.00	58.67
		LC_{90}	9.29	10.53	10.53	22.57
6	Ethofenprox	LC_{50}	12.86	23.68	22.50	30.00
		LC_{90}	7.06	8.00	8.00	17.14
7	Imidacloprid	LC_{50}	28.29	52.11	49.50	66.00
		LC_{90}	33.65	38.13	38.13	81.71
8	Thiamethoxam	LC_{50}	28.86	53.16	50.50	67.33
		LC_{90}	14.00	15.87	15.87	34.00

Table 4.29. Order of toxicity of novel insecticides against *N. lugens* of West Godavari population.

Season	At LC_{50}	At LC_{90}
2008-09	Buprofezin (0.00014) > Pymetrozine (0.00018)= Imidacloprid +Ethiprole (0.00018) > Ethiprole (0.00035).	Buprofezin (0.00091) > Pymetrozine (0.0015) = Ethiprole (0.0015) > Imidacloprid+Ethiprole (0.001816).
2009-10	Buprofezin (0.00015) > Pymetrozine (0.00019) > Imidacloprid +Ethiprole (0.0002) > Ethiprole (0.00035).	Buprofezin (0.0007) > Pymetrozine (0.0015) = Imidacloprid +Ethiprole (0.0015) > Ethiprole (0.0017).

Table 4.30. Duration of nymphal instars of different populations of *N. lugens* (2008-09).

S. No.	BPH population of	No. of instars	Duration of instars (days)				
			I	II	III	IV	V
1	Susceptible	5	3.04 (2 - 5)*	2.20 (1 - 4)	2.40 (1 - 3)	2.32 (1 - 3)	3.24 (2 - 5)
2	East Godavari	5	3.20 (2 - 4)	2.24 (1 - 3)	2.72 (2 - 4)	2.72 (2 - 4)	3.68 (2 - 5)
3	West Godavari	5	3.36 (2 - 4)	2.24 (1 - 3)	2.52 (1 - 4)	2.88 (2 - 4)	3.68 (2 - 5)
4	Karimnagar	5	3.32 (2 - 4)	2.32 (1 - 3)	2.36 (1 - 4)	2.84 (2 - 4)	3.72 (2 - 4)
S.E ± mean			0.15	0.51	0.34	0.16	0.52
CD			NS	NS	NS	NS	NS

*The values in parenthesis are range.

Table 4.31. Duration of nymphal instars of different populations of *N. lugens* (2009-10).

S. No.	BPH population of	No. of instars	Duration of instars (days)				
			I	II	III	IV	V
1.	Susceptible	5	2.92 (2 - 4)*	1.96 (1 - 3)	2.32 (1 - 3)	2.12 (1 - 3)	3.16 (2 - 5)
2.	East Godavari	5	3.20 (2 - 4)	2.12 (1 - 3)	2.48 (1 - 4)	2.64 (2 - 4)	3.80 (2 - 5)
3.	West Godavari	5	3.28 (2 - 4)	2.44 (1 - 3)	2.52 (1 - 3)	2.84 (2 - 4)	3.68 (2 - 5)
4.	Karimnagar	5	3.16 (2 - 4)	2.40 (1 - 3)	2.56 (2 - 4)	2.96 (2 - 4)	3.72 (2 - 5)
S.E. ± mean			0.14	0.17	0.13	0.16	0.20
CD			NS	NS	NS	NS	NS

*The values in parenthesis are range.

Table 4.32. Biological parameters of different populations of *N. lugens* (2008-09).

Biological parameter	BPH population of				S.E.±mean	CD
	Susceptible	East Godavari	West Godavari	Karimnagar		
Egg period (days)	6.20 (6 - 7)*	6.56 (6 - 8)	6.92 (6 - 8)	6.92 (6 - 9)	0.12	0.37
No. of progeny (Number)	183 (50 - 325)	167 (60 - 360)	164 (62 - 360)	169 (67 - 340)	13.95	NS
Total nymphal period (days)	13.2 (11.8 - 14.8)	14.56 (13.8 - 16.2)	14.68 (14 - 15.8)	14.56 (13.8 - 15.2)	0.41	NS
Pre oviposition period (days)	3.04 (2 - 4)	3.40 (2 - 4)	3.56 (2 - 4)	3.52 (2 - 4)	0.11	NS
Oviposition period (days)	4.40 (3 - 5)	3.84 (3 - 5)	3.92 (3 - 5)	3.92 (3 - 5)	0.13	NS
Adult longevity (B.F) (days)	19.36 (15 - 24)	18.36 (15 - 24)	17.08 (13 - 25)	18.20 (13 - 24)	0.80	NS
Adult longevity (M.M) (days)	17.36 (15 - 23)	17.00 (14 - 22)	16.84 (12 - 23)	16.80 (12 - 22)	0.64	NS
Total life cycle (B.F) (days)	38.62 (36 - 40.4)	39.48 (36.8 - 42.4)	38.68 (36 - 41.4)	39.68 (37.4 - 41.2)	0.86	NS

B.F - Brachypterous female; M.M - Macropterous male; B.F - Brachypterous female.
* The values in parenthesis are range.

Table 4.33. Biological parameters of different populations of *N. lugens* (2009-10).

Biological parameter	BPH population of				S.E.±mean	CD
	Susceptible	East Godavari	West Godavari	Karimnagar		
Egg period (days)	6.24 (6 - 7) *	6.84 (6 - 8)	6.88 (6 - 8)	6.84 (6 - 8)	0.10	0.31
No. of progeny (Number)	151 (55 - 262)	148 (62 - 323)	135 (60 - 220)	130 (67 - 270)	14.66	NS
Total nymphal period (days)	12.48 (11.6 - 13.6)	14.24 (13.5 - 15)	14.76 (13.2 - 15.6)	14.80 (13.8 - 15.4)	0.35	1.06
Pre-oviposition period (days)	3.08 (2 - 4)	3.36 (2 - 4)	3.72 (3 - 4)	3.48 (3 - 4)	0.14	NS
Oviposition period (days)	4.32 (3 - 6)	4.00 (3 - 6)	3.96 (3 - 5)	3.80 (3 - 5)	0.18	NS
Adult longevity (B.F) (days)	18.44 (15 - 24)	17.80 (14-25)	18.12 (10 - 24)	17.20 (13-24)	0.97	NS
Adult longevity (M.M) (days)	18.40 (15 - 23)	17.00 (12 - 23)	17.08 (13 - 24)	17.24 (12 - 23)	0.67	NS
Total life cycle (B.F) (days)	37.16 (35 - 38.8)	38.88 (36.4 - 41.0)	39.76 (37 - 42.2)	38.84 (34.6 - 40.8)	0.92	NS

B.F - Brachypterous female; M.M - Macropterous male.
* The values in parenthesis are range.

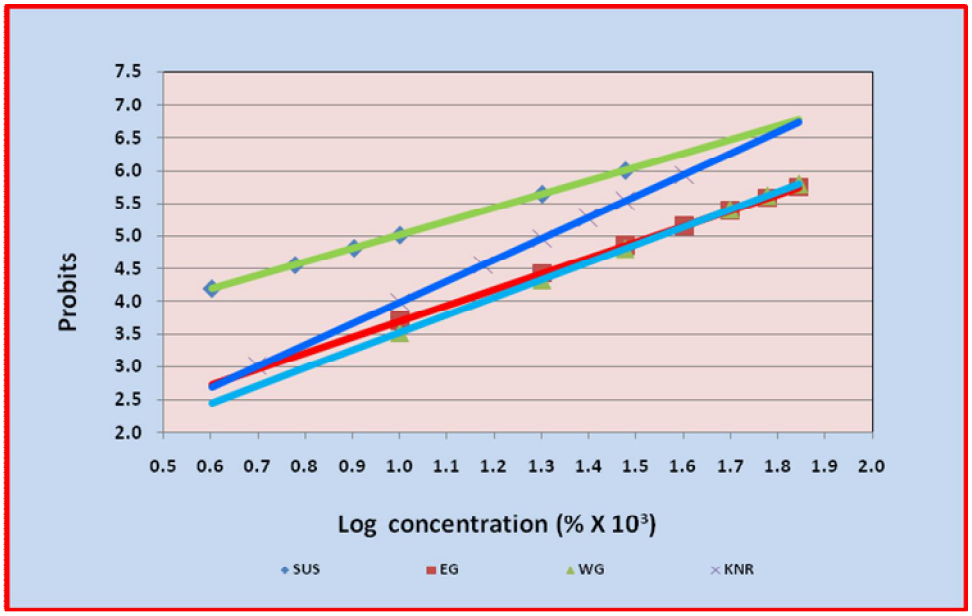


Fig. 4.1. Log concentration probit lines of different populations of *N. lugens* to endosulfan (2008-09)

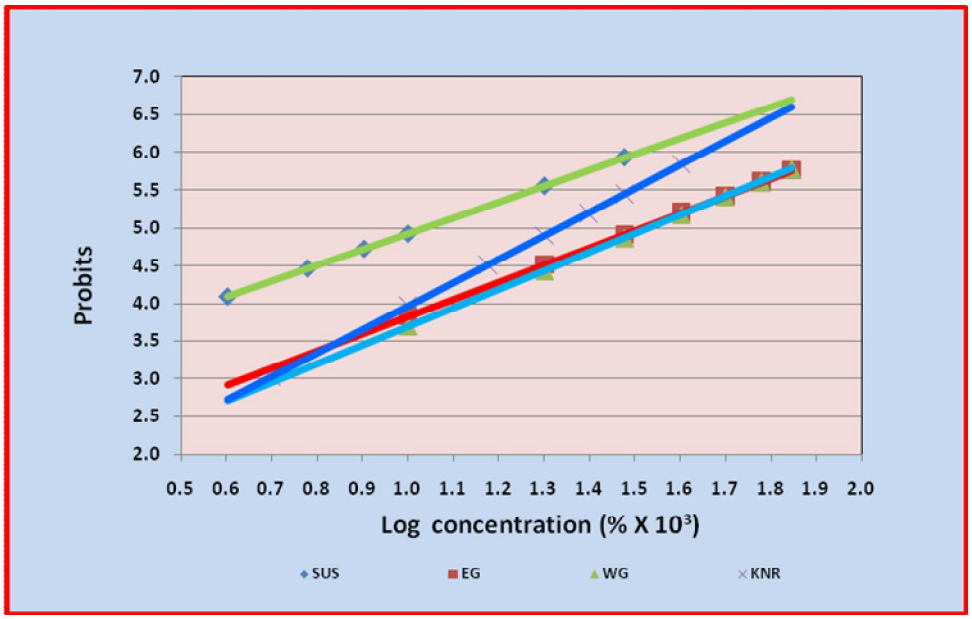


Fig. 4.2. Log concentration probit lines of different populations of *N. lugens* to endosulfan (2009-10)

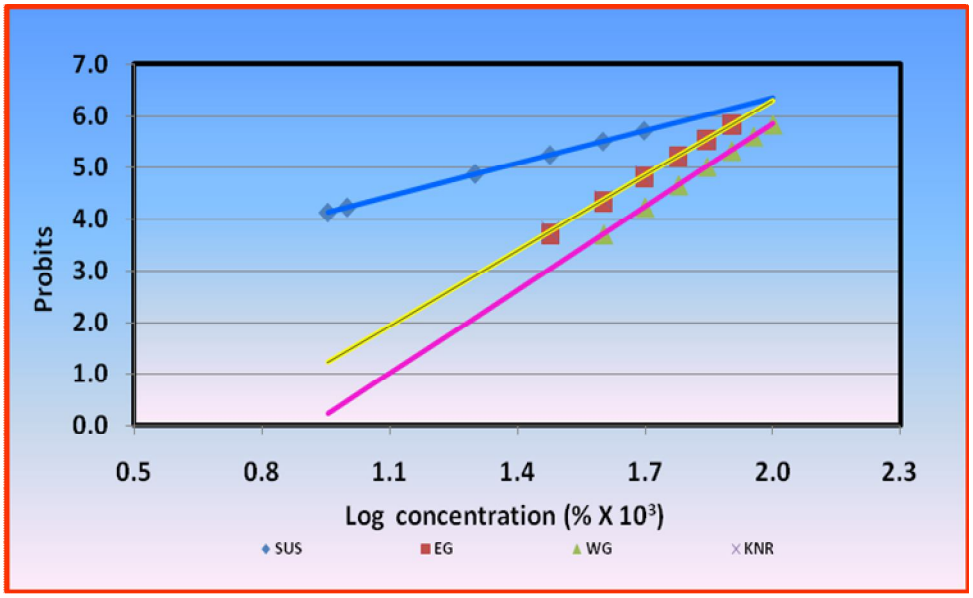


Fig. 4.3. Log concentration probit lines of different populations of *N. lugens* to monocrotophos (2008-09)

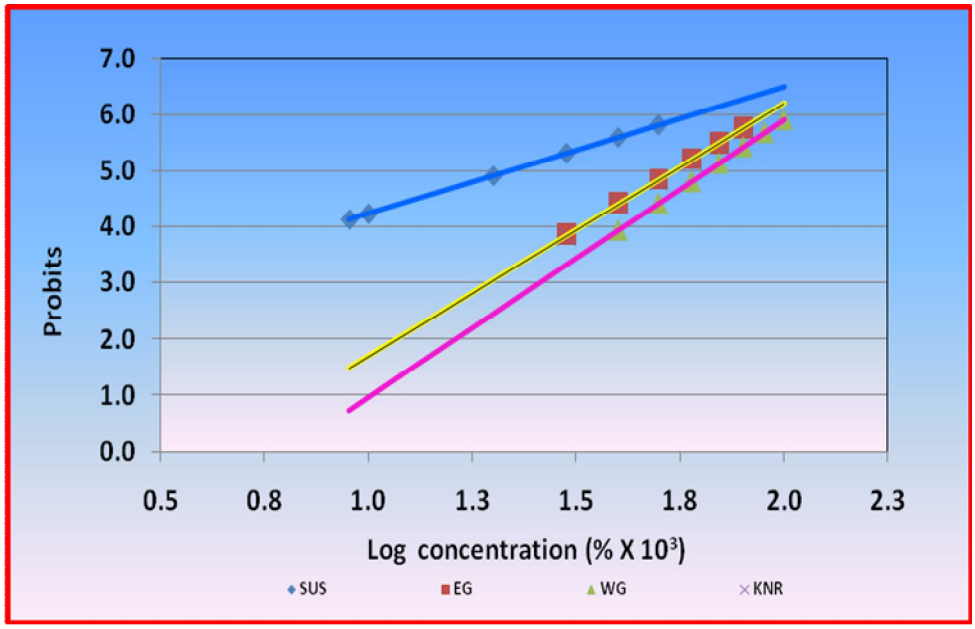


Fig. 4.4. Log concentration probit lines of different populations of *N. lugens* to monocrotophos (2009-10)

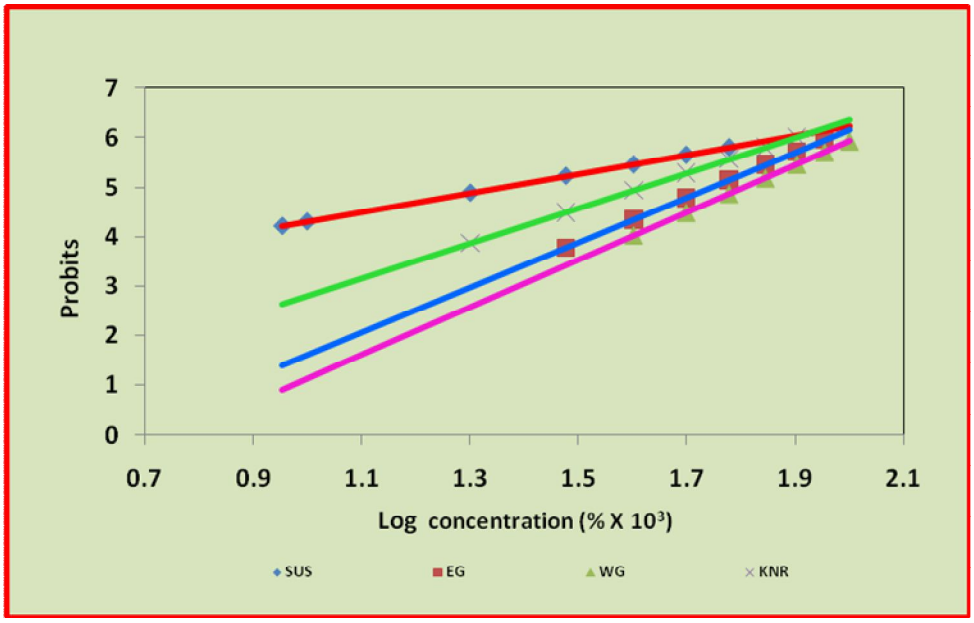


Fig. 4.5. Log concentration probit lines of different populations of *N. lugens* to acephate (2008-09)

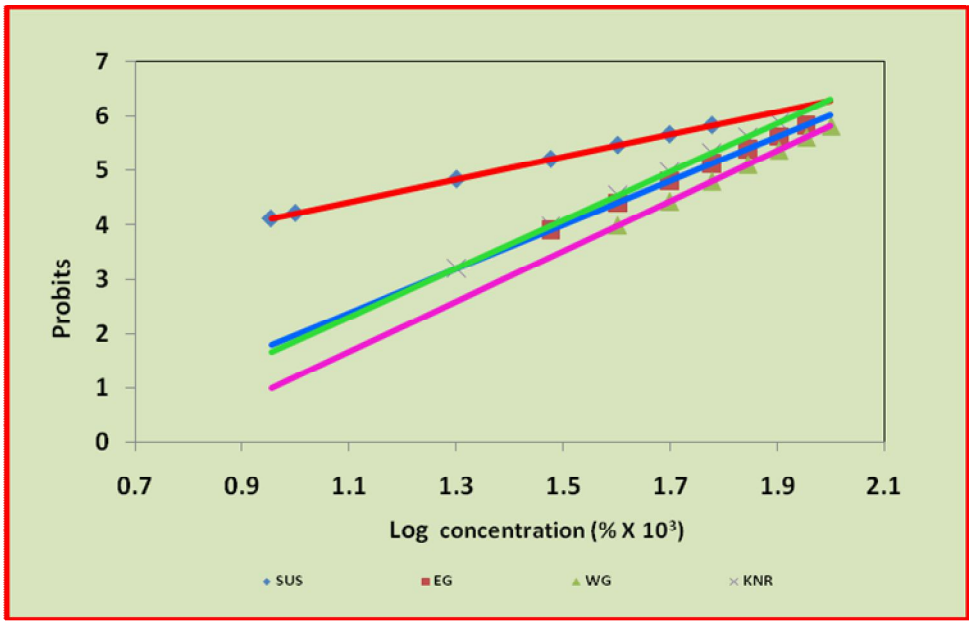


Fig. 4.6. Log concentration probit lines of different populations of *N. lugens* to acephate (2009-10)

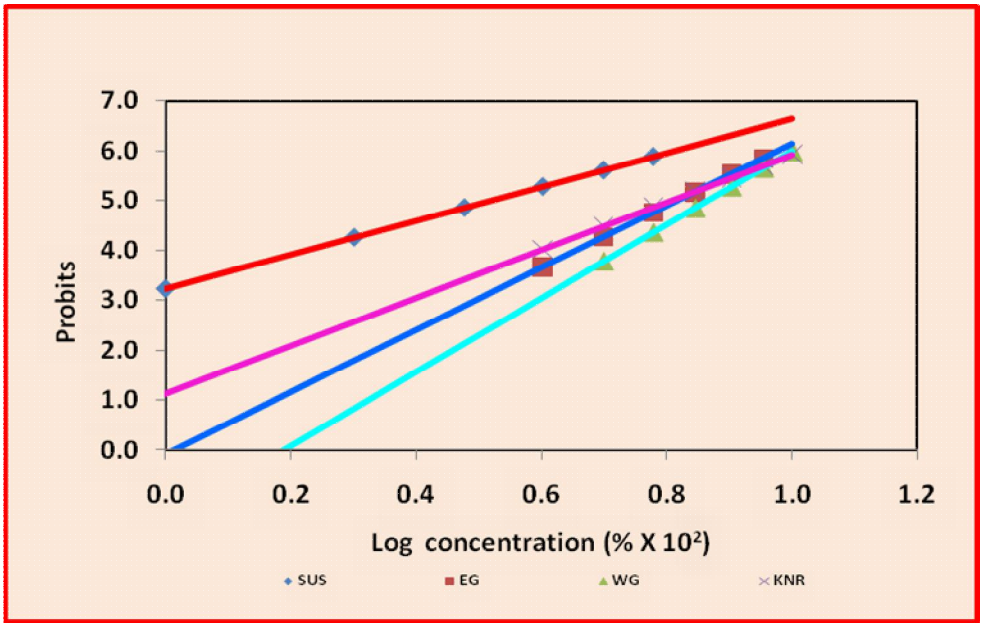


Fig. 4.7. Log concentration probit lines of different populations of *N. lugens* to phosphamidon (2008-09)

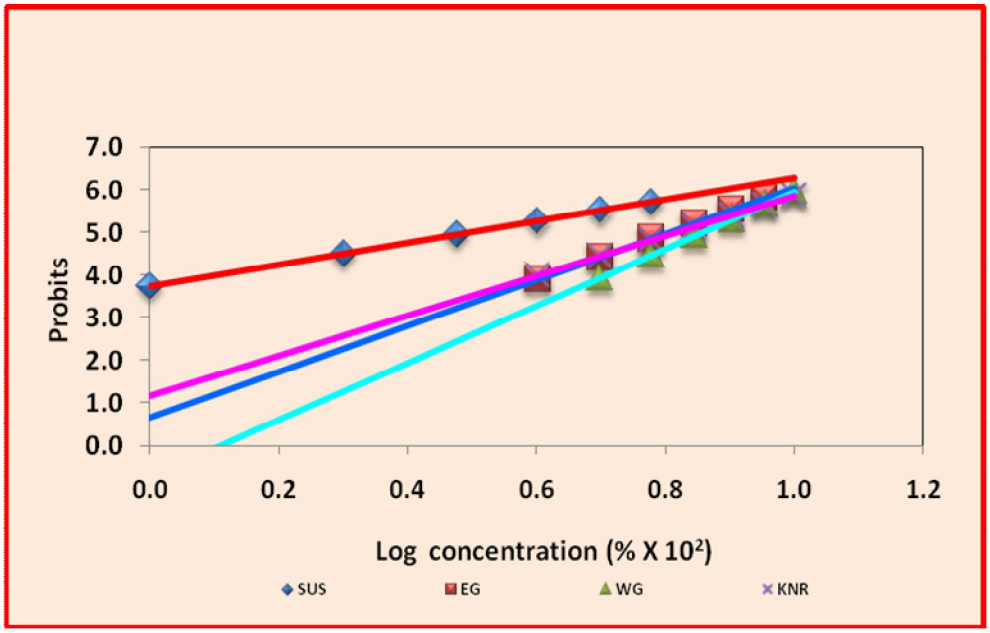


Fig. 4.8. Log concentration probit lines of different populations of *N. lugens* to phosphamidon (2009-10)

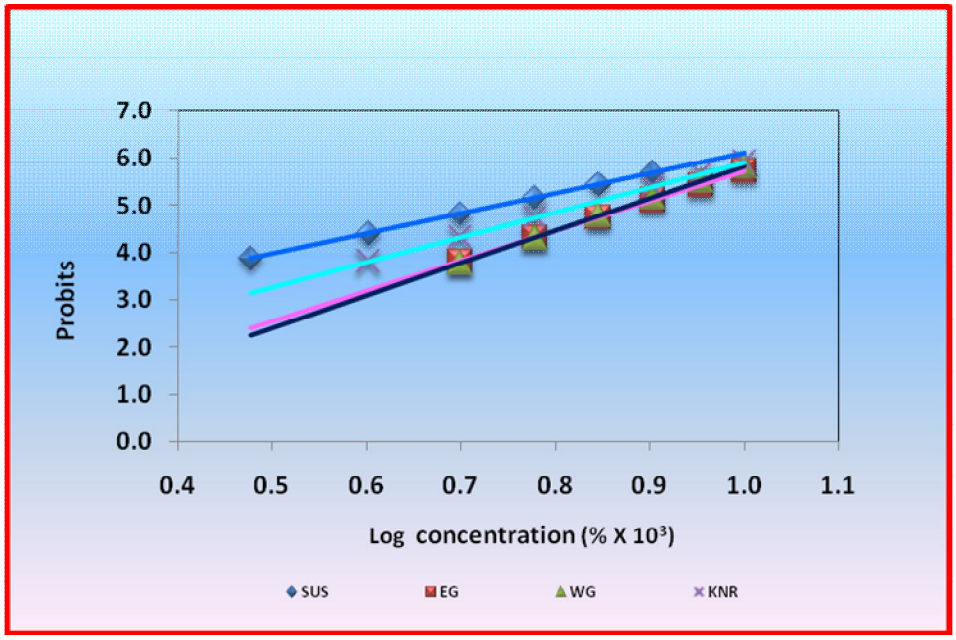


Fig. 4.9. Log concentration probit lines of different populations of *N. lugens* to fenobucarb (2008-09)

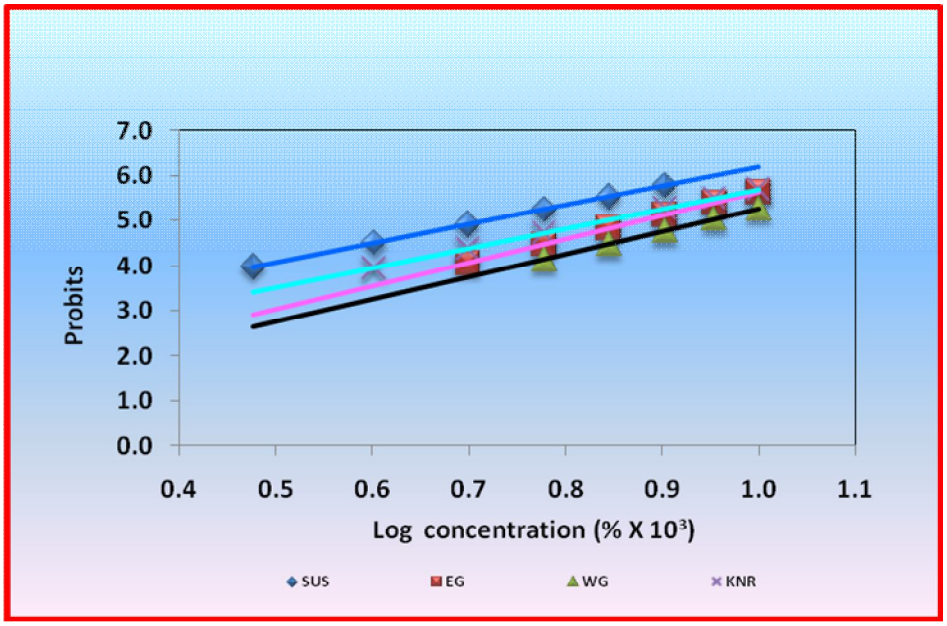


Fig. 4.10. Log concentration probit lines of different populations of *N. lugens* to fenobucarb (2009-10)

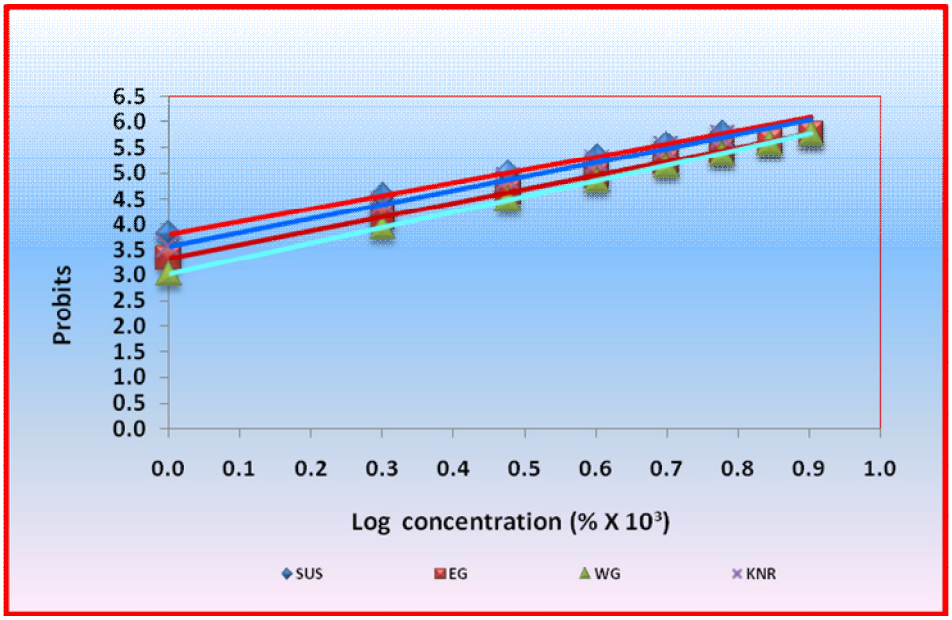


Fig. 4.11. Log concentration probit lines of different populations of *N. lugens* to ethofenprox (2008-09)

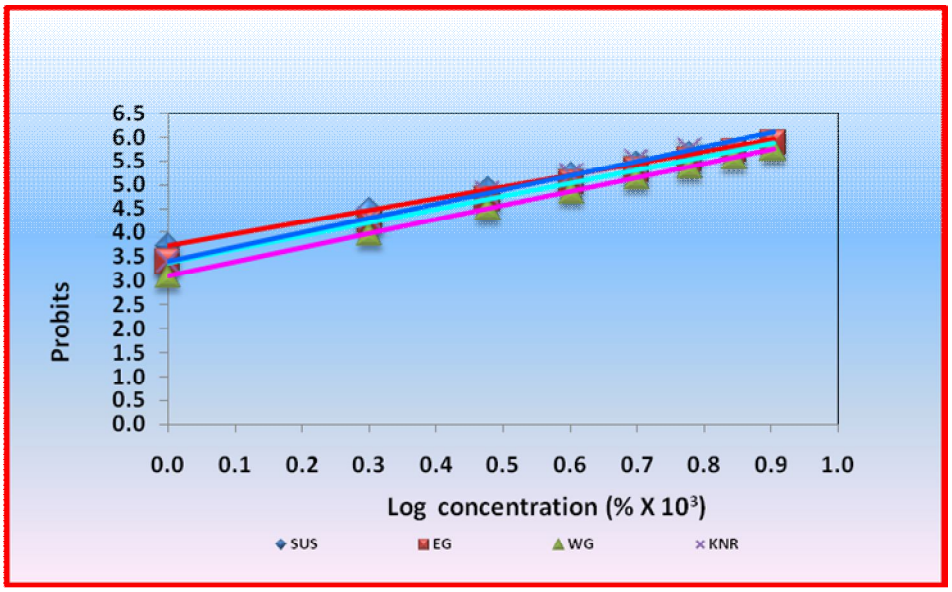


Fig. 4.12. Log concentration probit lines of different populations of *N. lugens* to ethofenprox (2009-10)

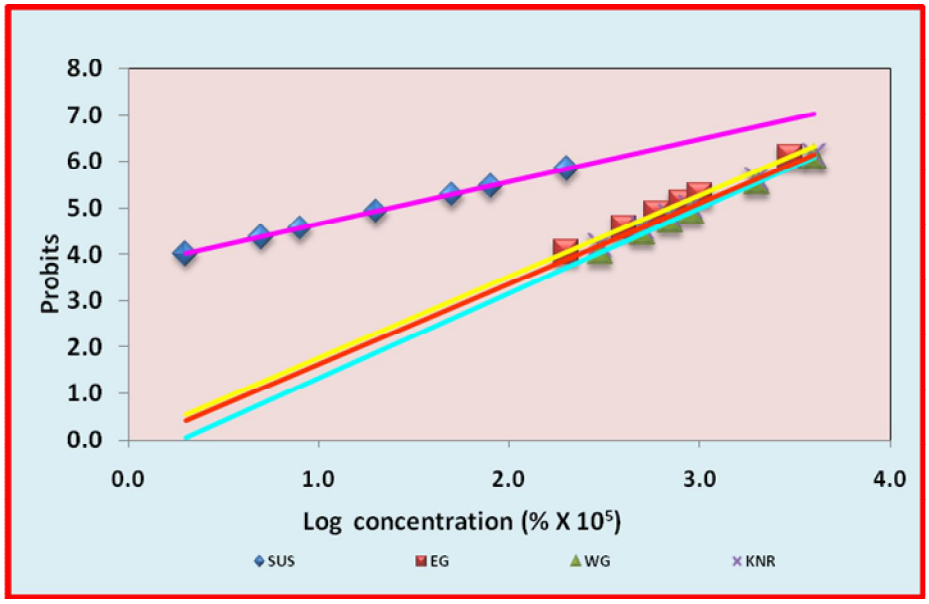


Fig. 4.13. Log concentration probit lines of different populations of *N. lugens* to imidacloprid (2008-09)

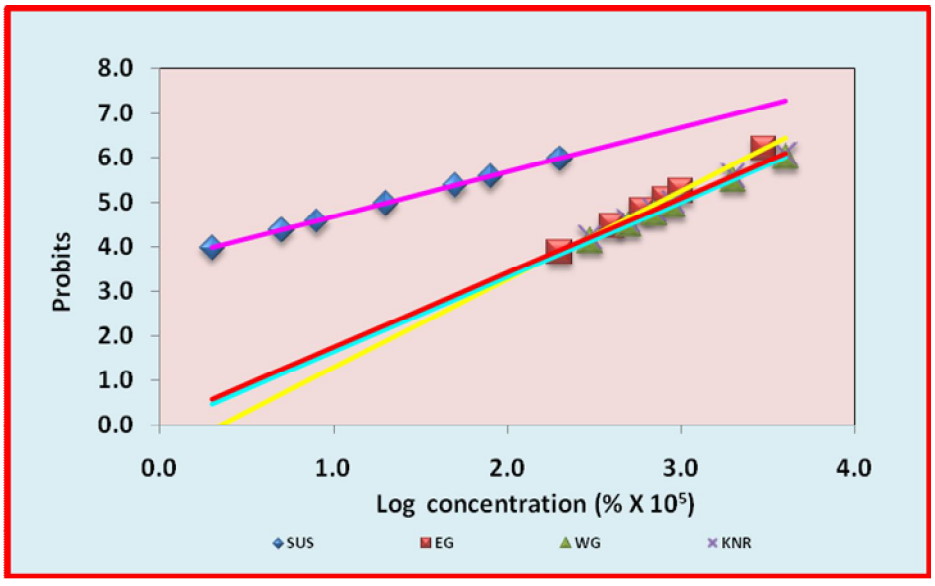


Fig. 4.14. Log concentration probit lines of different populations of *N. lugens* to imidacloprid (2009-10)

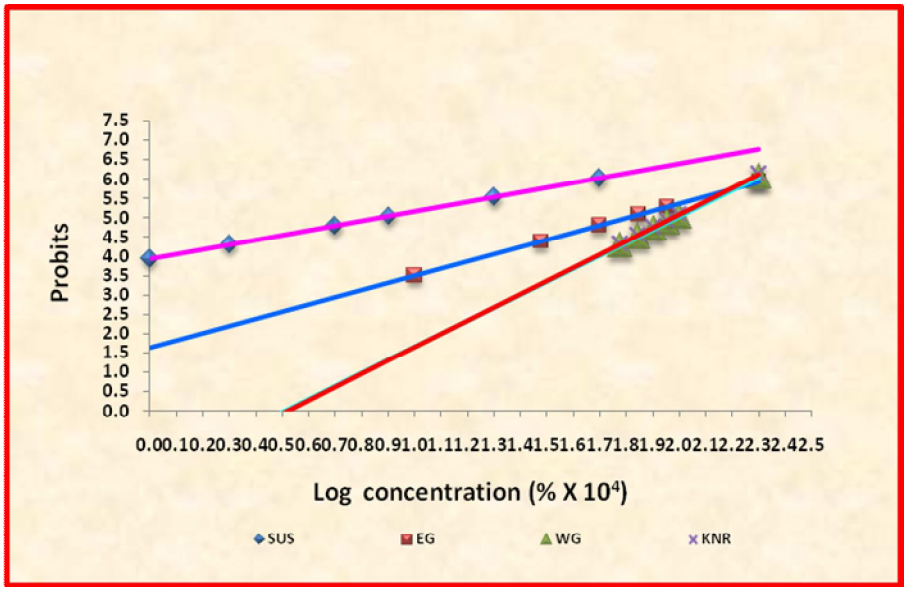


Fig. 4.15. Log concentration probit lines of different populations of *N. lugens* to thiamethoxam (2008-09)

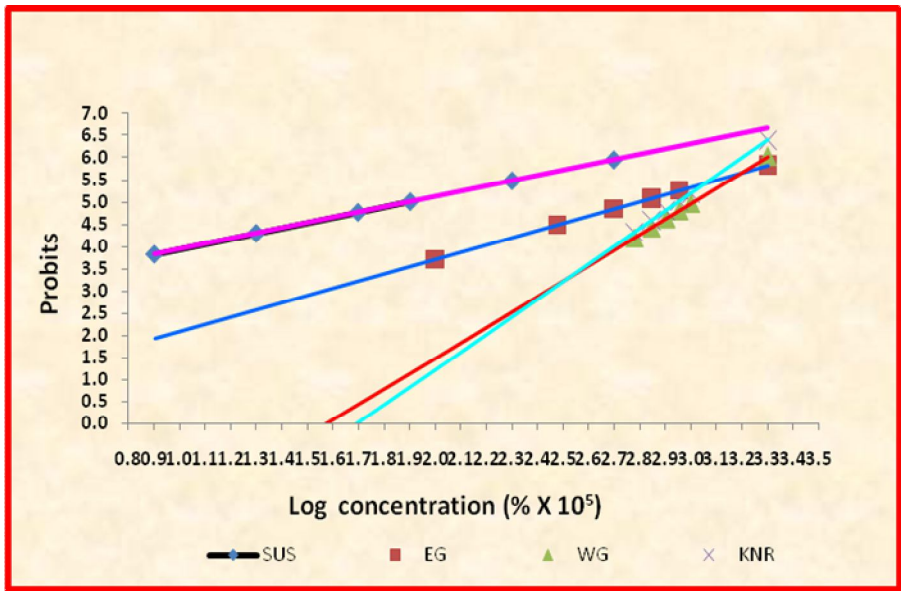


Fig. 4.16. Log concentration probit lines of different populations of *N. lugens* to thiamethoxam (2009-10)

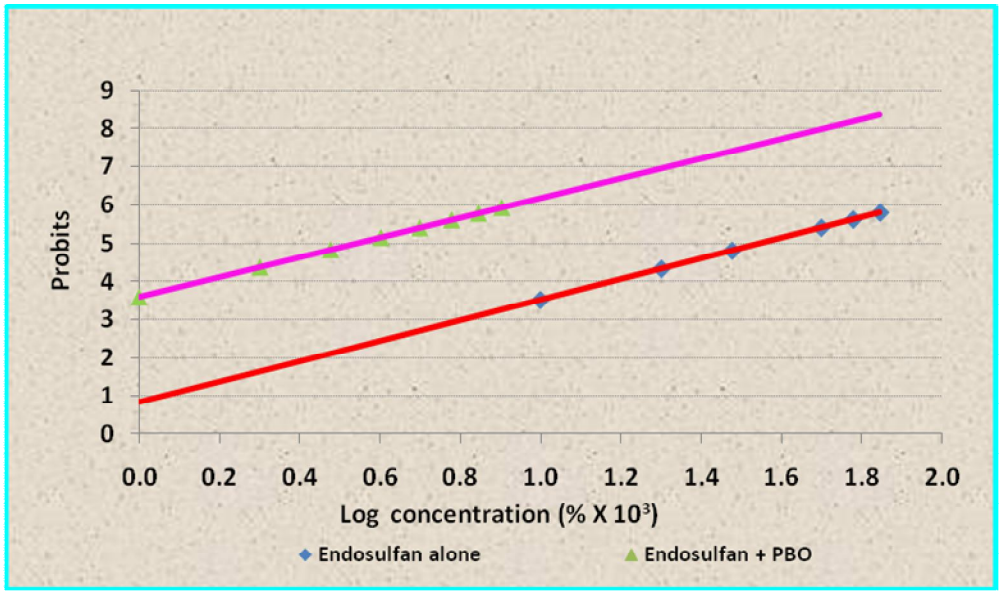


Fig. 4.17. Log concentration probit lines of West Godavari population of *N. lugens* to endosulfan and endosulfan + PBO (2008-09)

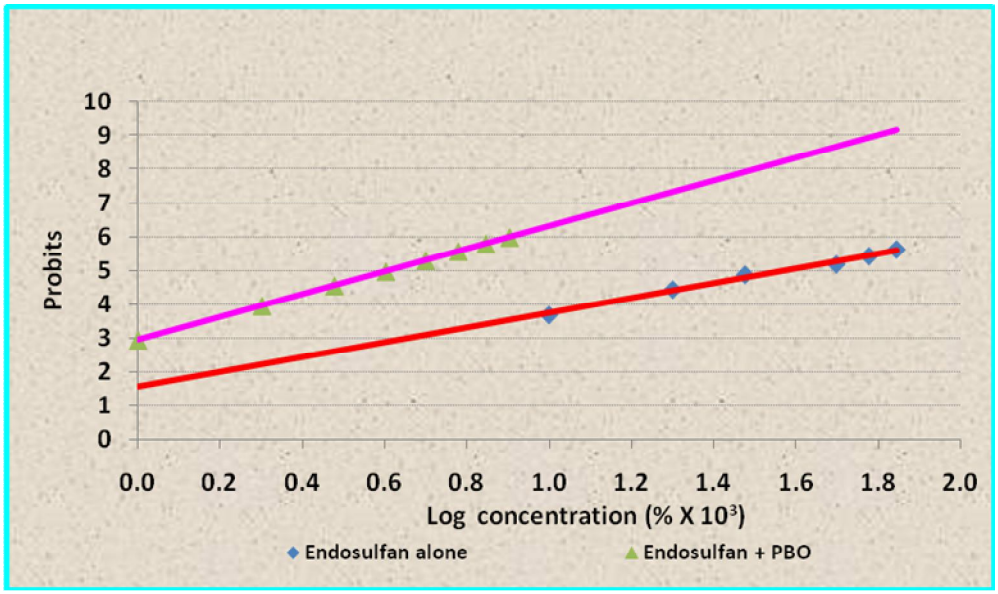


Fig. 4.18. Log concentration probit lines of West Godavari population of *N. lugens* to endosulfan and endosulfan + PBO (2009-10)

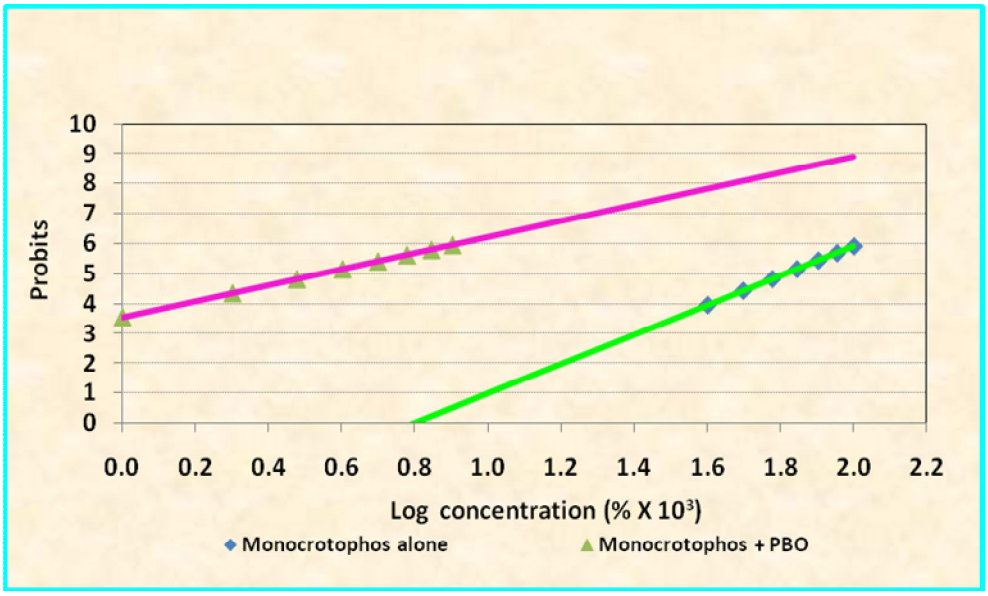


Fig. 4.19. Log concentration probit lines of West Godavari population of *N. lugens* to monocrotophos and monocrotophos + PBO (2008-09)

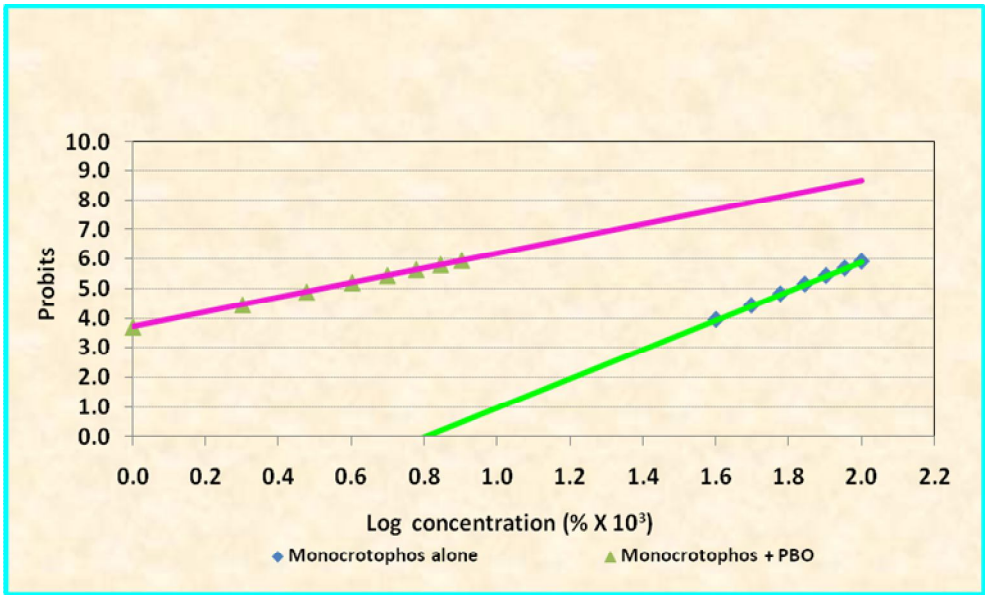


Fig. 4.20. Log concentration probit lines of West Godavari population of *N. lugens* to monocrotophos and monocrotophos + PBO (2009-10)

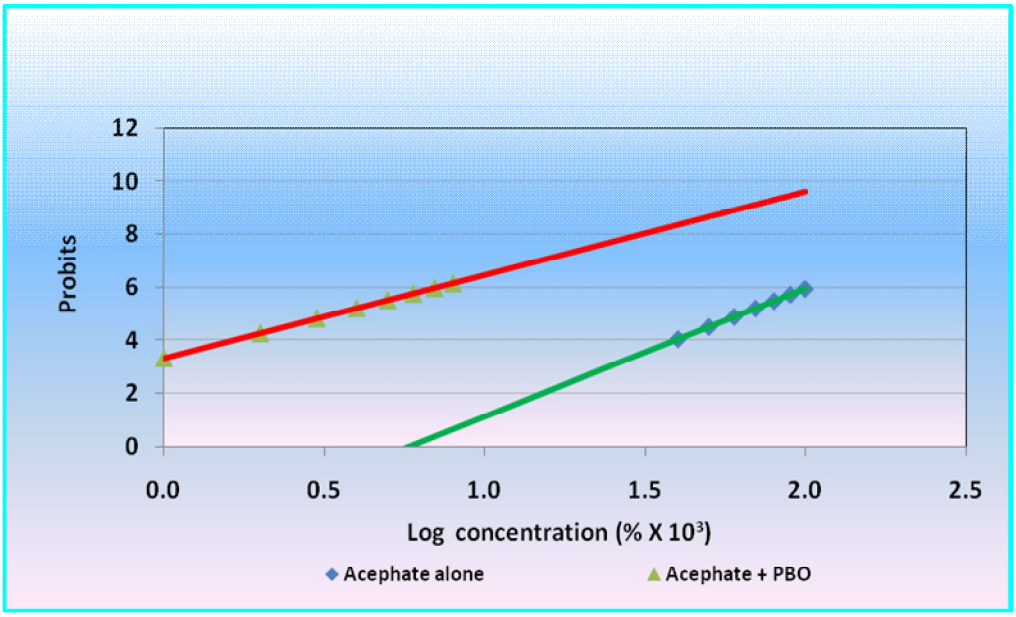


Fig. 4.21. Log concentration probit lines of West Godavari population of *N. lugens* to acephate and acephate + PBO (2008-09)

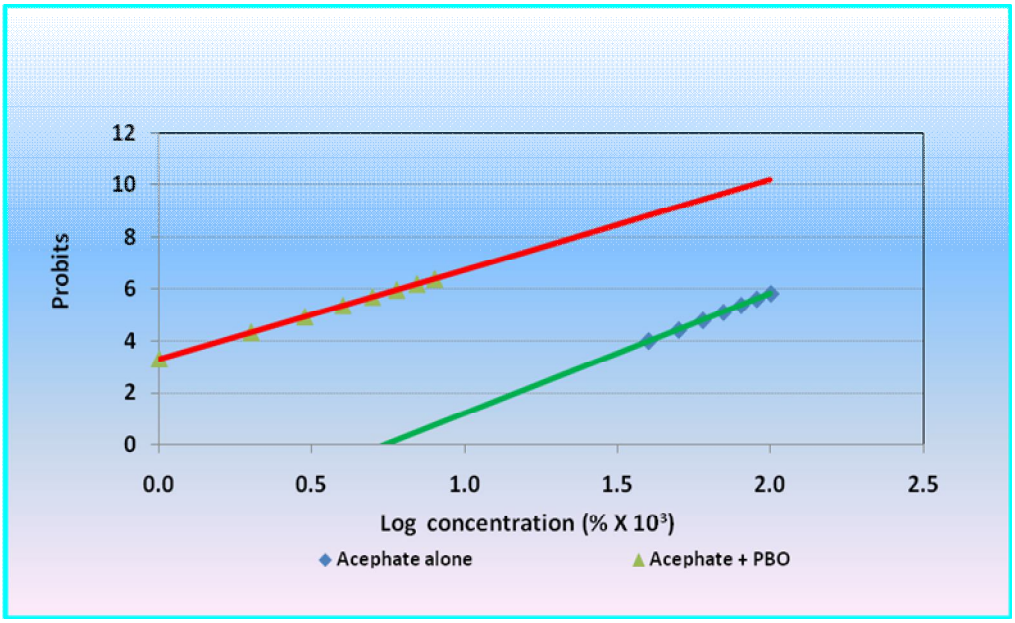


Fig. 4.22. Log concentration probit lines of West Godavari population of *N. lugens* to acephate and acephate + PBO (2009-10)

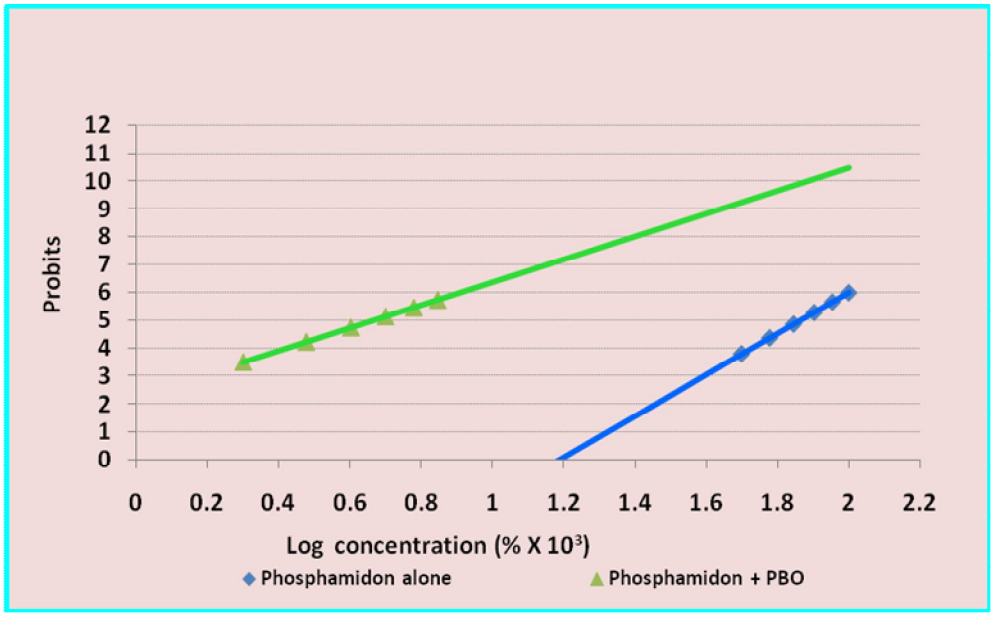


Fig. 4.23. Log concentration probit lines of West Godavari population of *N. lugens* to phosphamidon and phosphamidon + PBO (2008-09)

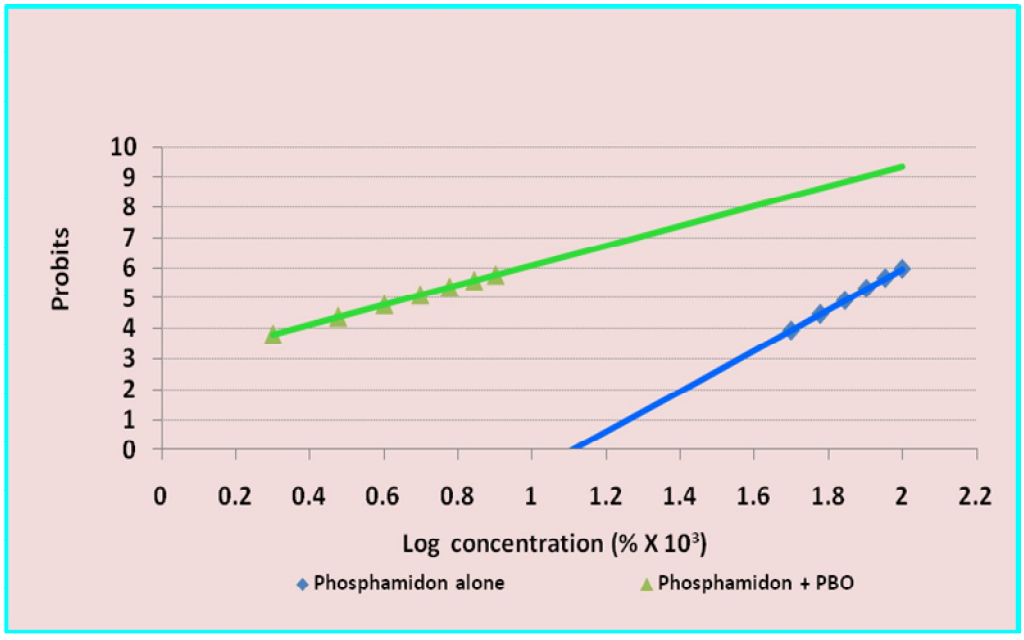


Fig. 4.24. Log concentration probit lines of West Godavari population of *N. lugens* to phosphamidon and phosphamidon + PBO (2009-10)

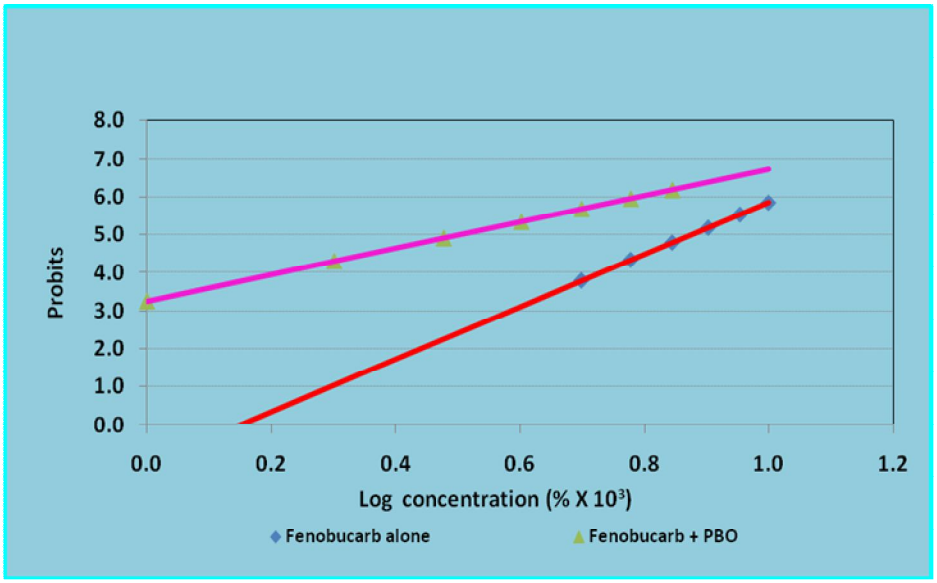


Fig. 4.25. Log concentration probit lines of West Godavari population of *N. lugens* to fenobucarb and fenobucarb + PBO (2008-09)

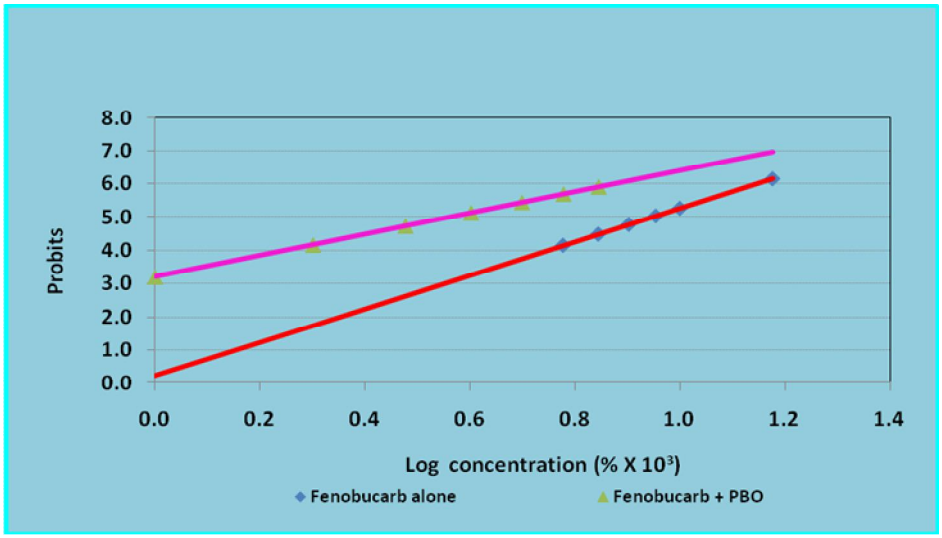


Fig. 4.26. Log concentration probit lines of West Godavari population of *N. lugens* to fenobucarb and fenobucarb + PBO (2009-10)

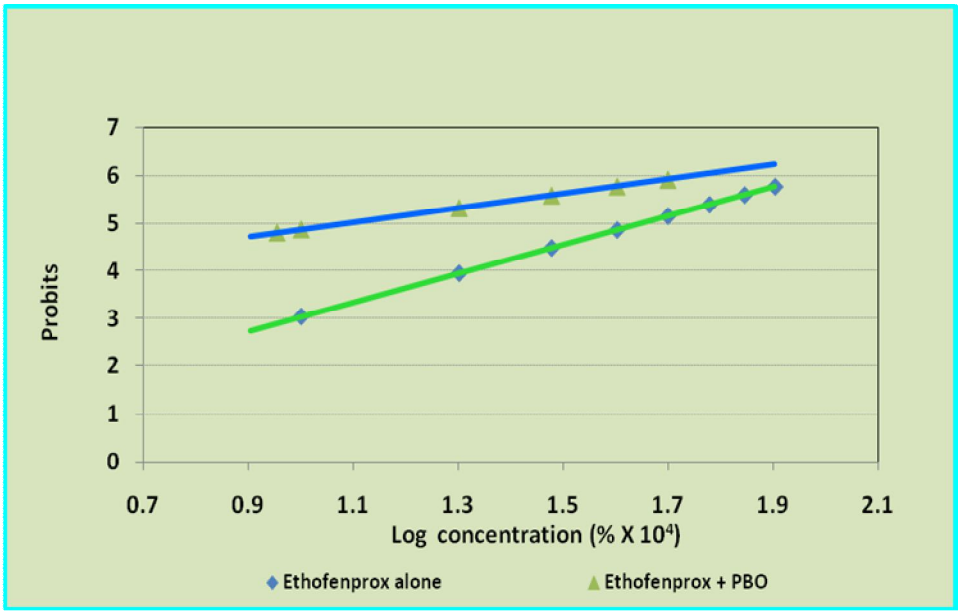


Fig. 4.27. Log concentration probit lines of West Godavari population of *N. lugens* to ethofenprox and ethofenprox + PBO (2008-09)

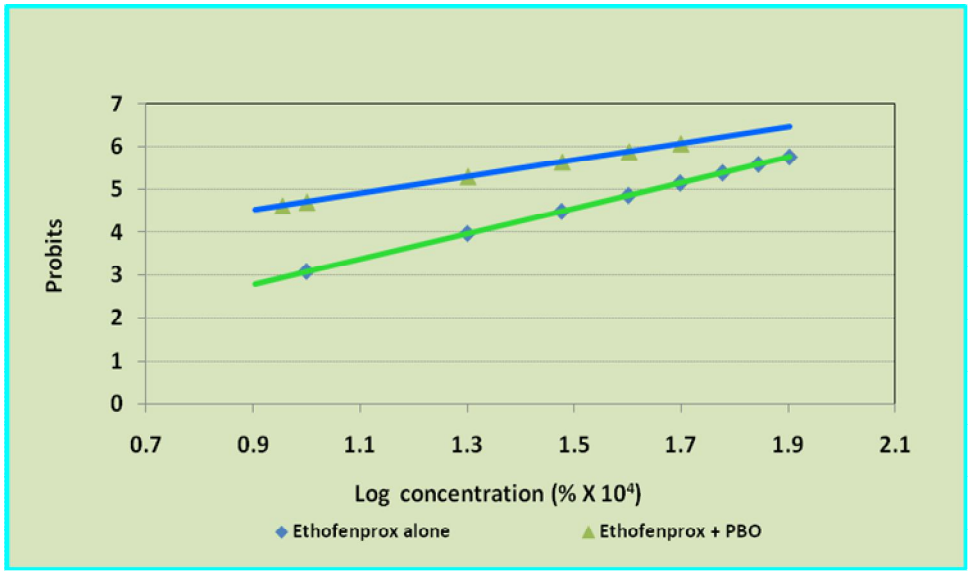


Fig. 4.28. Log concentration probit lines of West Godavari population of *N. lugens* to ethofenprox and ethofenprox + PBO (2009-10)

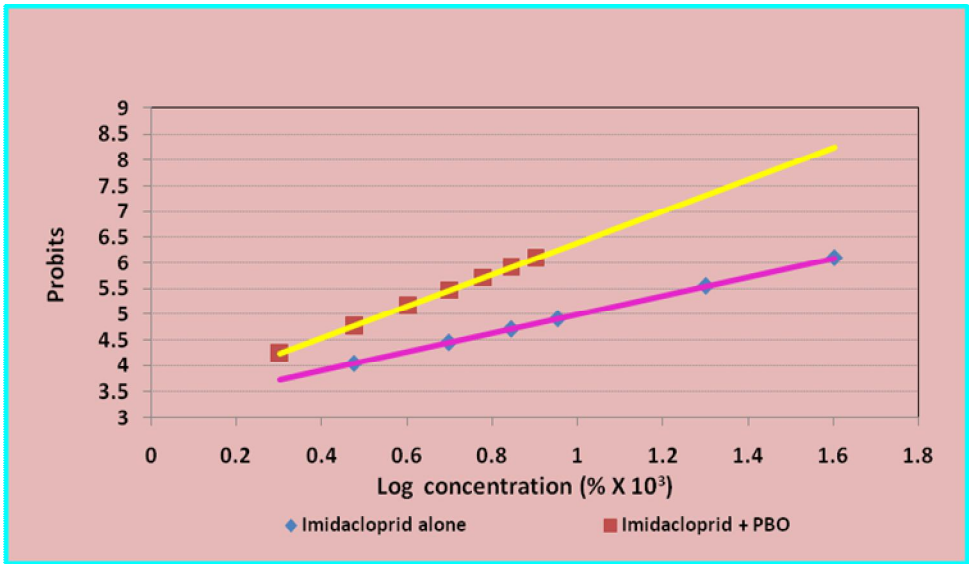


Fig. 4.29. Log concentration probit lines of West Godavari population of *N. lugens* to imidacloprid and imidacloprid + PBO (2008-09)

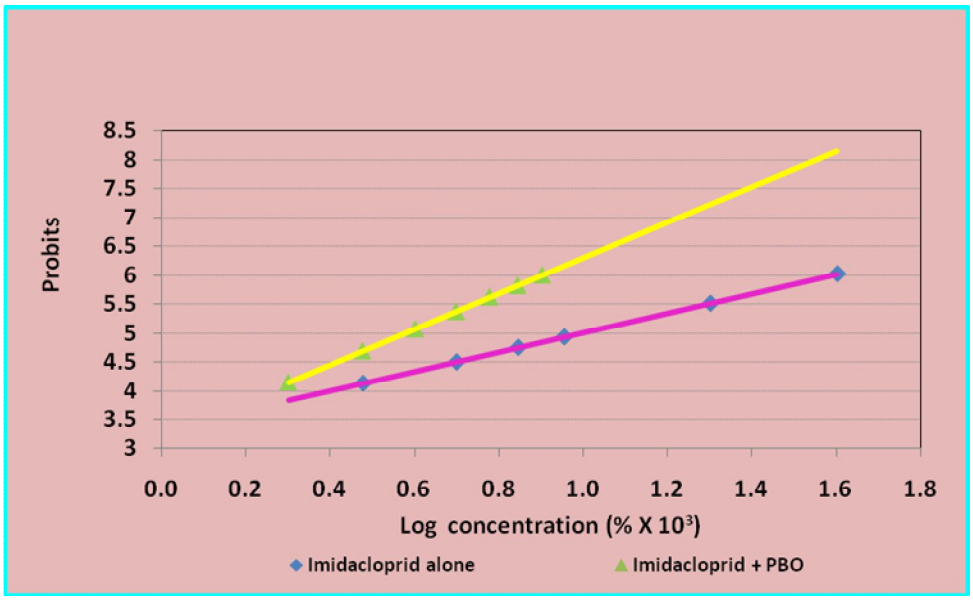


Fig. 4.30. Log concentration probit lines of West Godavari population of *N. lugens* to imidacloprid and imidacloprid + PBO (2009-10)

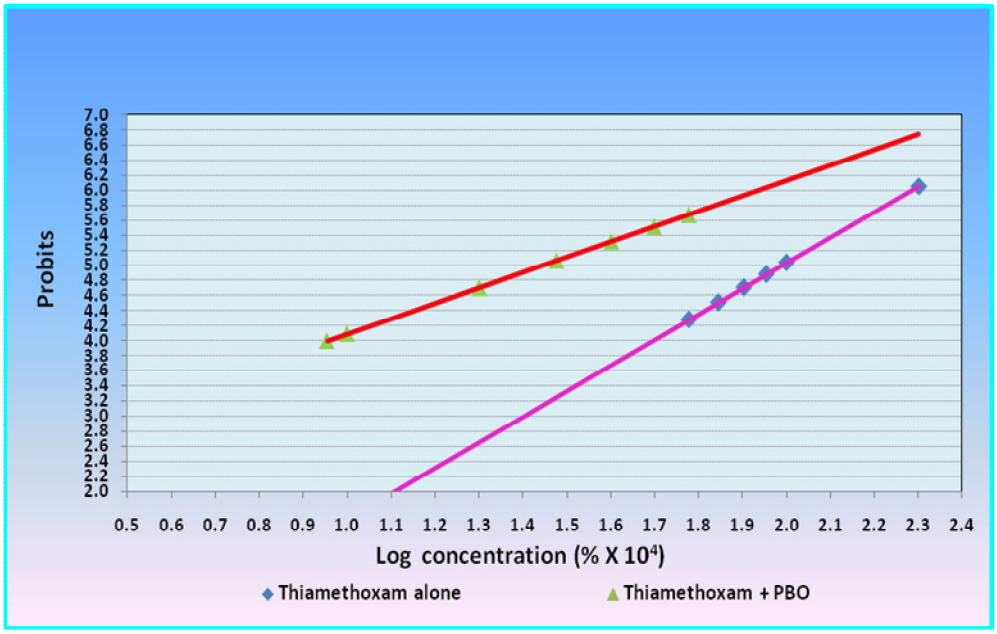


Fig. 4.31. Log concentration probit lines of West Godavari population of *N. lugens* to thiamethoxam and thiamethoxam + PBO (2008-09)

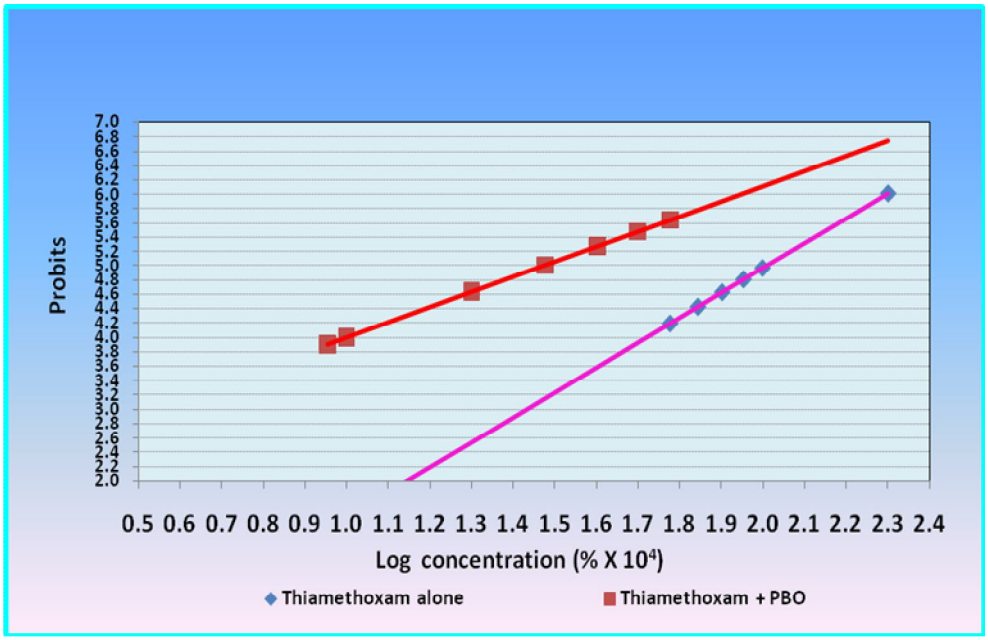


Fig. 4.32. Log concentration probit lines of West Godavari population of *N. lugens* to thiamethoxam and thiamethoxam + PBO (2009-10)

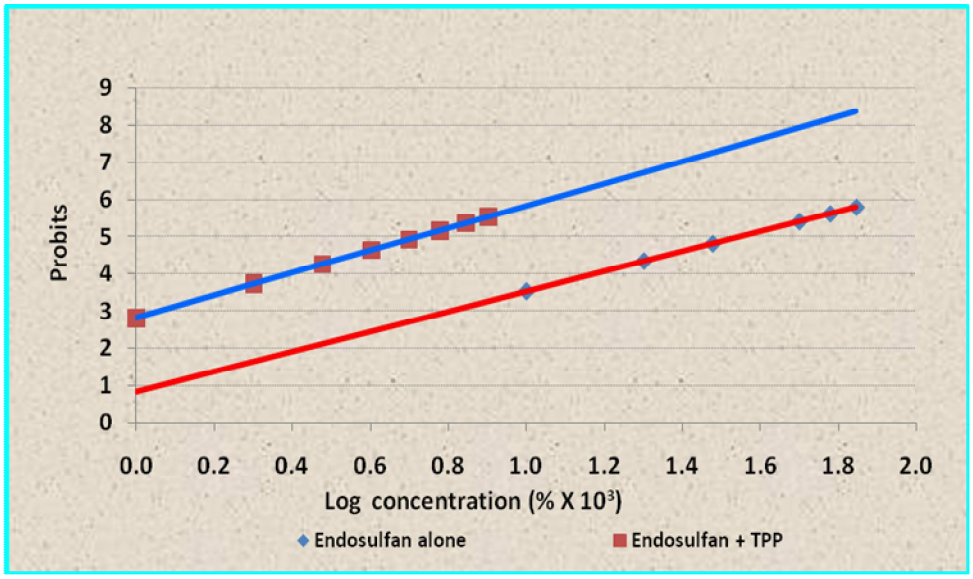


Fig. 4.33. Log concentration probit lines of West Godavari population of *N. lugens* to endosulfan and endosulfan + TPP (2008-09)

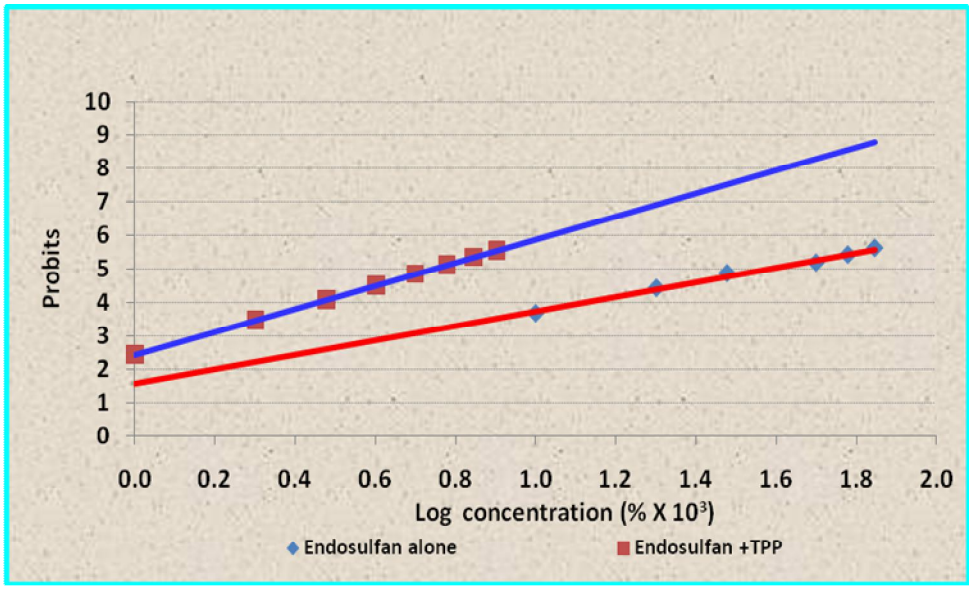


Fig. 4.34. Log concentration probit lines of West Godavari population of *N. lugens* to endosulfan and endosulfan + TPP (2009-10)

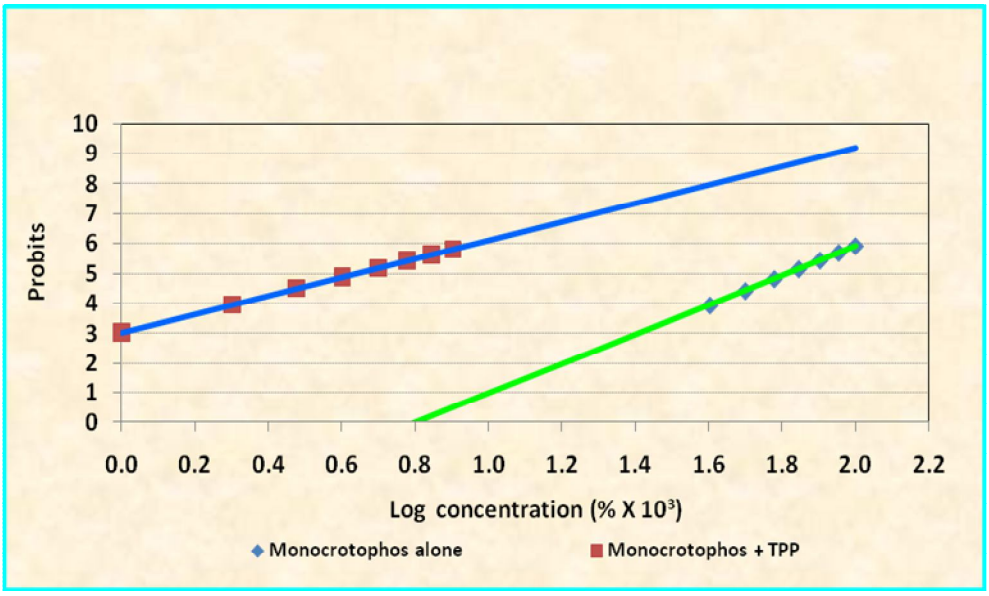


Fig. 4.35. Log concentration probit lines of West Godavari population of *N. lugens* to monocrotophos and monocrotophos + TPP (2008-09)

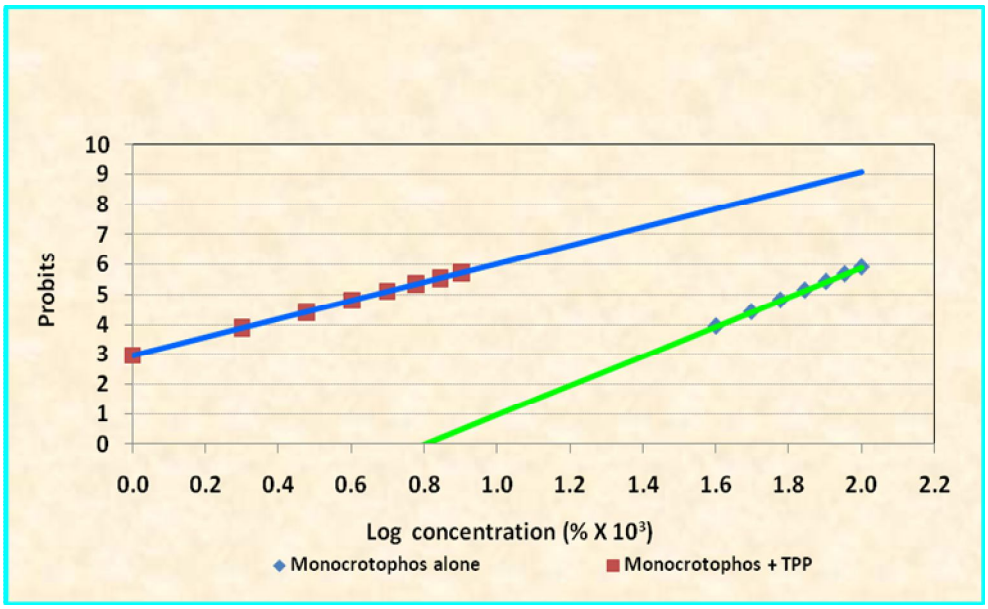


Fig. 4.36. Log concentration probit lines of West Godavari population of *N. lugens* to monocrotophos and monocrotophos + TPP (2009-10)

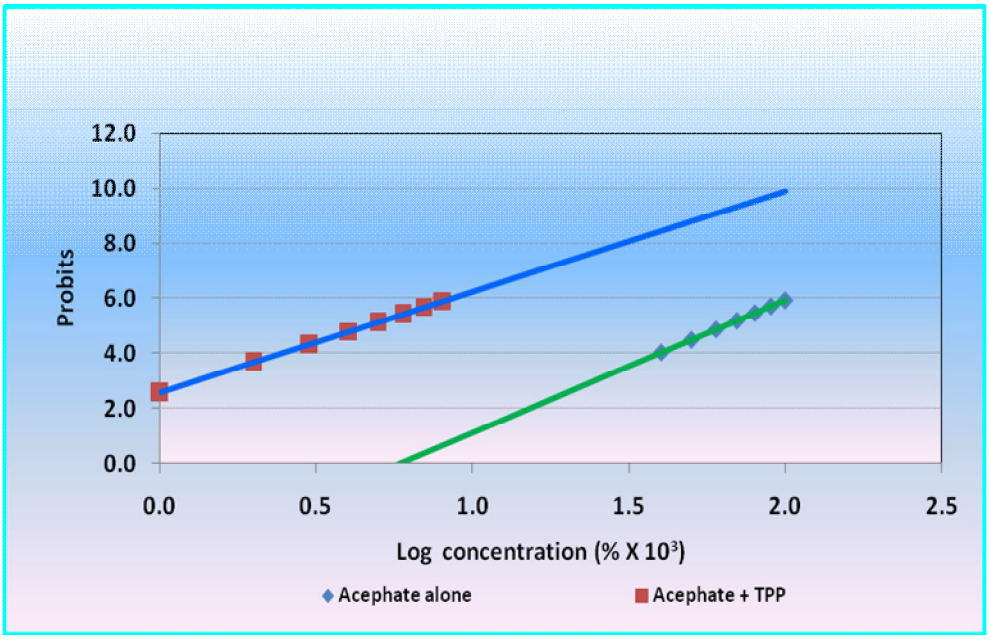


Fig. 4.37. Log concentration probit lines of West Godavari population of *N. lugens* to acephate and acephate + TPP (2008-09)

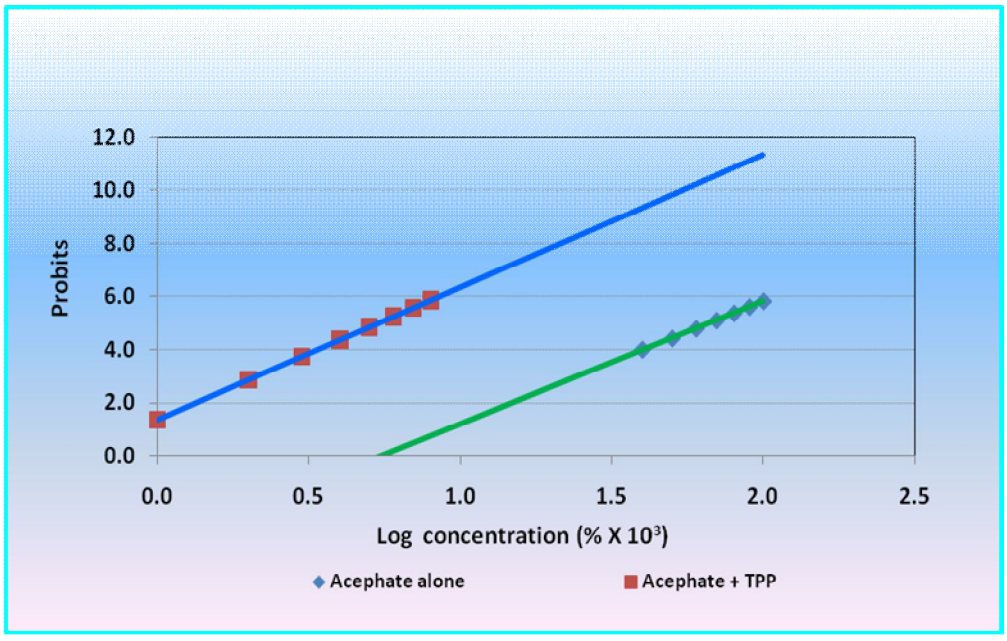


Fig. 4.38. Log concentration probit lines of West Godavari population of *N. lugens* to acephate and acephate + TPP (2009-10)

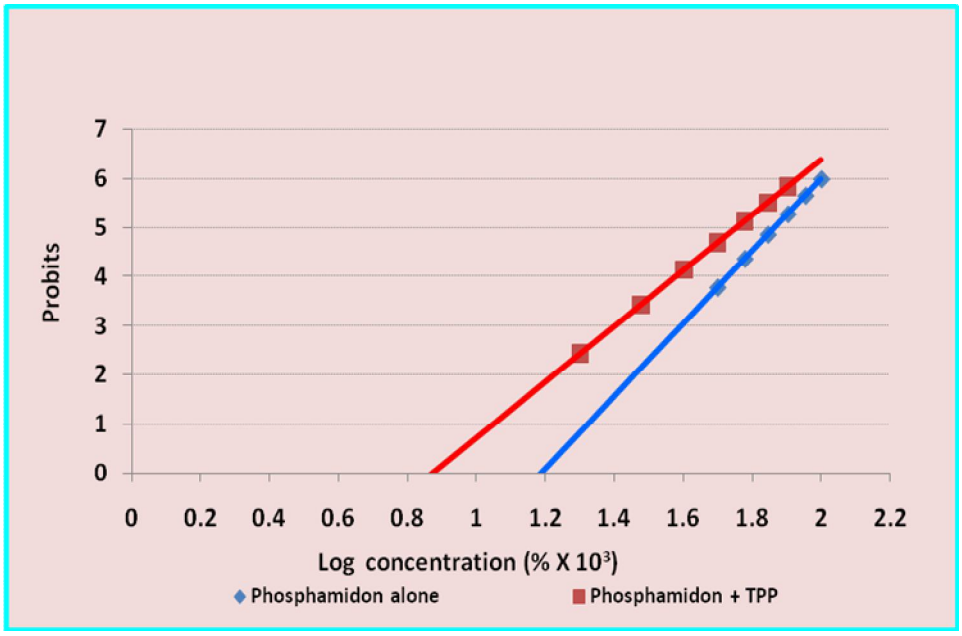


Fig. 4.39. Log concentration probit lines of West Godavari population of *N. lugens* to phosphamidon and phosphamidon + TPP (2008-09)

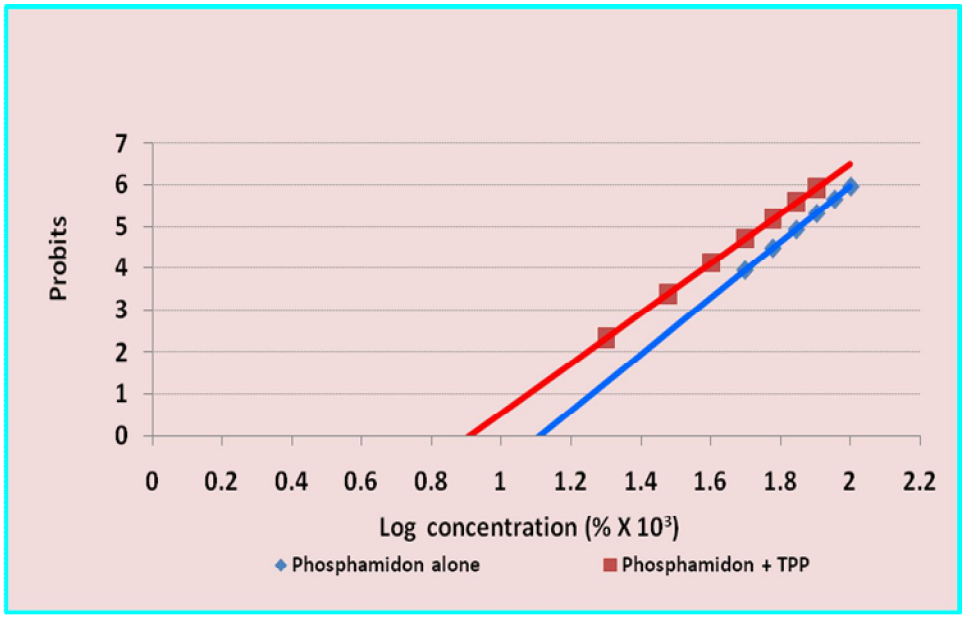


Fig. 4.40. Log concentration probit lines of West Godavari population of *N. lugens* to phosphamidon and phosphamidon + TPP (2009-10)

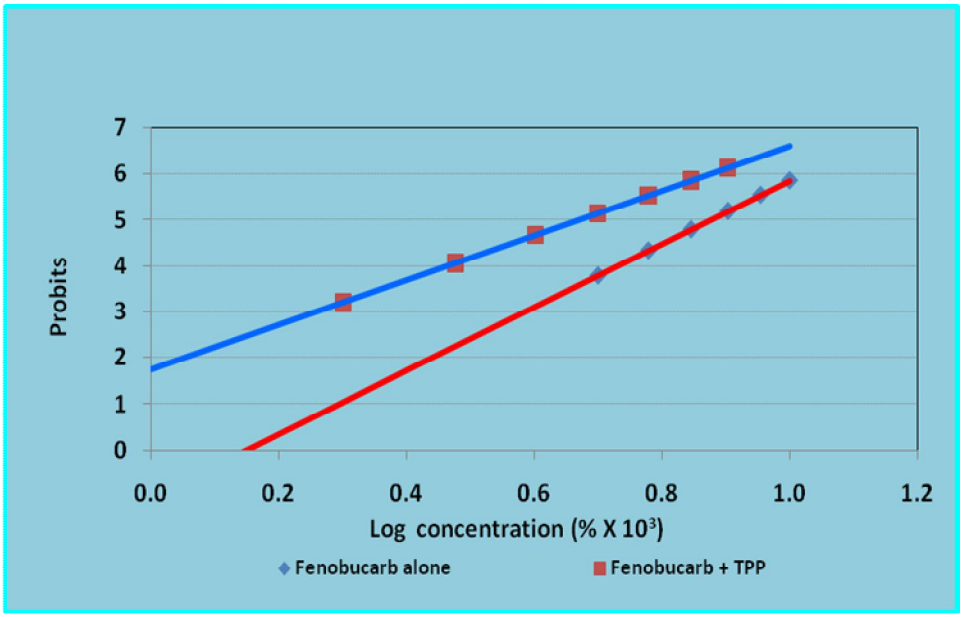


Fig. 4.41. Log concentration probit lines of West Godavari population of *N. lugens* to fenobucarb and fenobucarb + TPP (2008-09)

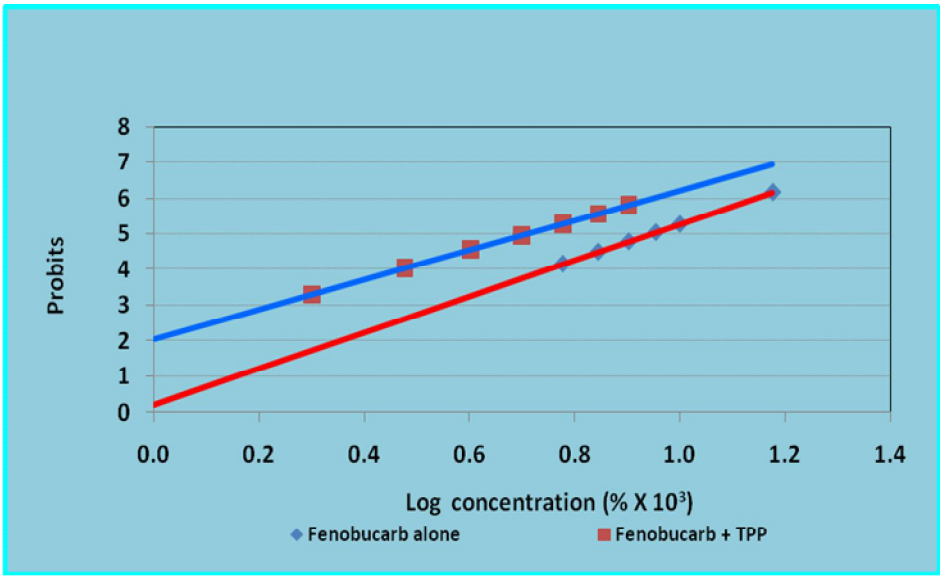


Fig. 4.42. Log concentration probit lines of West Godavari population of *N. lugens* to fenobucarb and fenobucarb + TPP (2009-10)

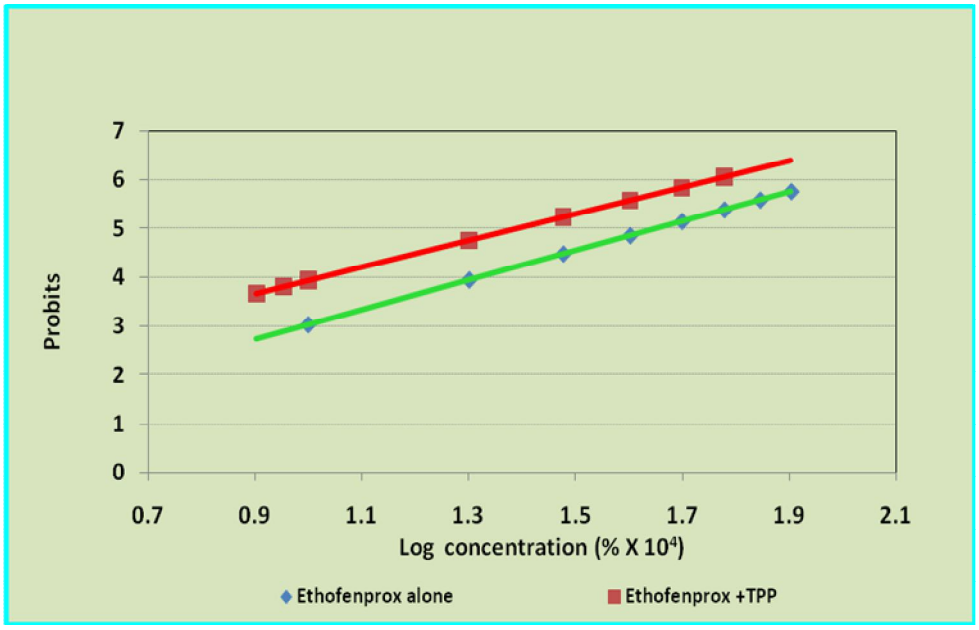


Fig. 4.43. Log concentration probit lines of West Godavari population of *N. lugens* to ethofenprox and ethofenprox + TPP (2008-09)

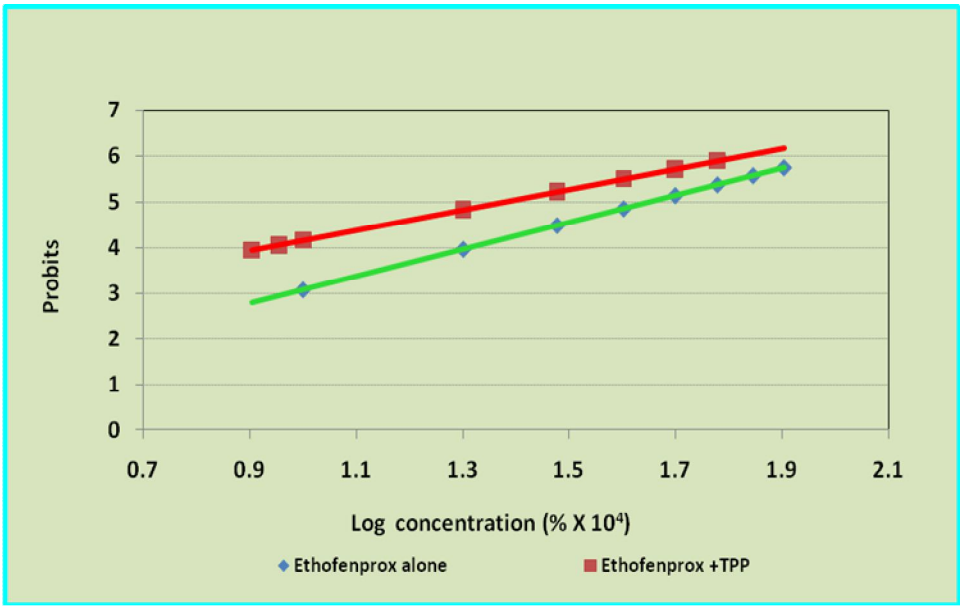


Fig. 4.44. Log concentration probit lines of West Godavari population of *N. lugens* to ethofenprox and ethofenprox + TPP (2009-10)

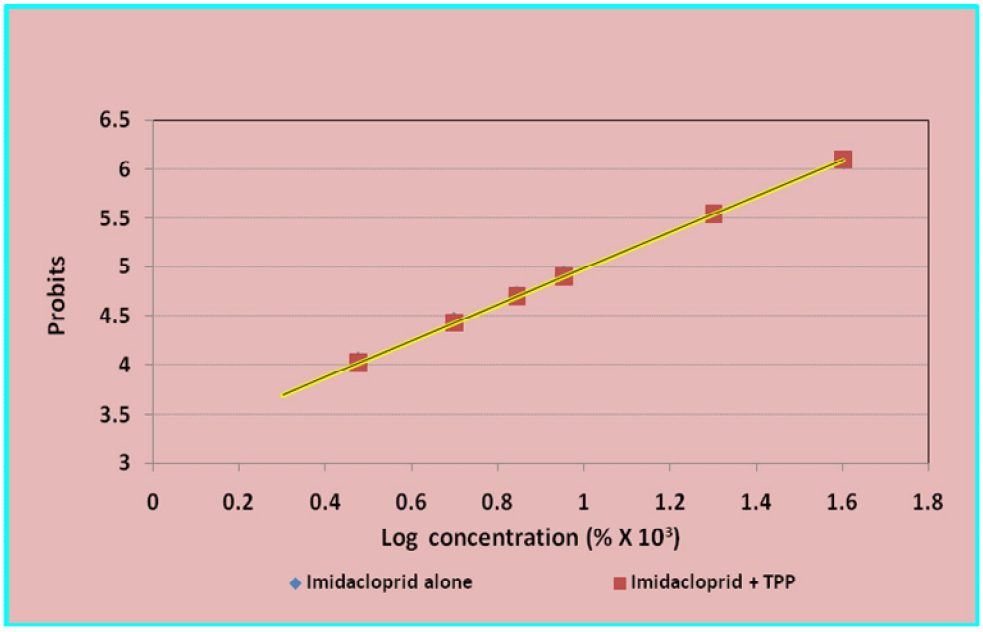


Fig. 4.45. Log concentration probit lines of West Godavari population of *N. lugens* to imidacloprid and imidacloprid + TPP (2008-09)

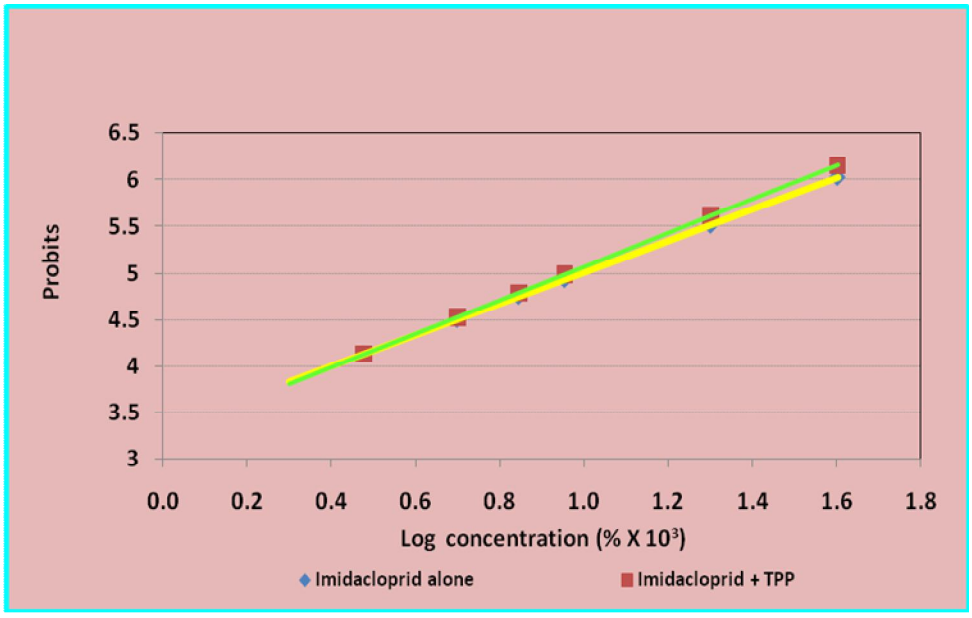


Fig. 4.46. Log concentration probit lines of West Godavari population of *N. lugens* to imidacloprid and imidacloprid + TPP (2009-10)

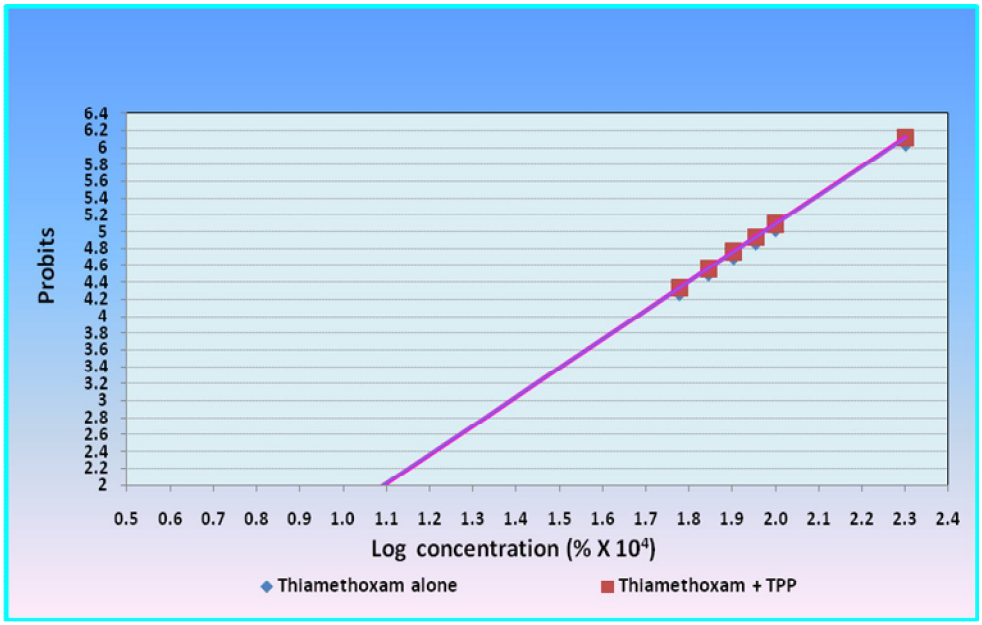


Fig. 4.47. Log concentration probit lines of West Godavari population of *N. lugens* to thiamethoxam and thiamethoxam + TPP (2008-09)

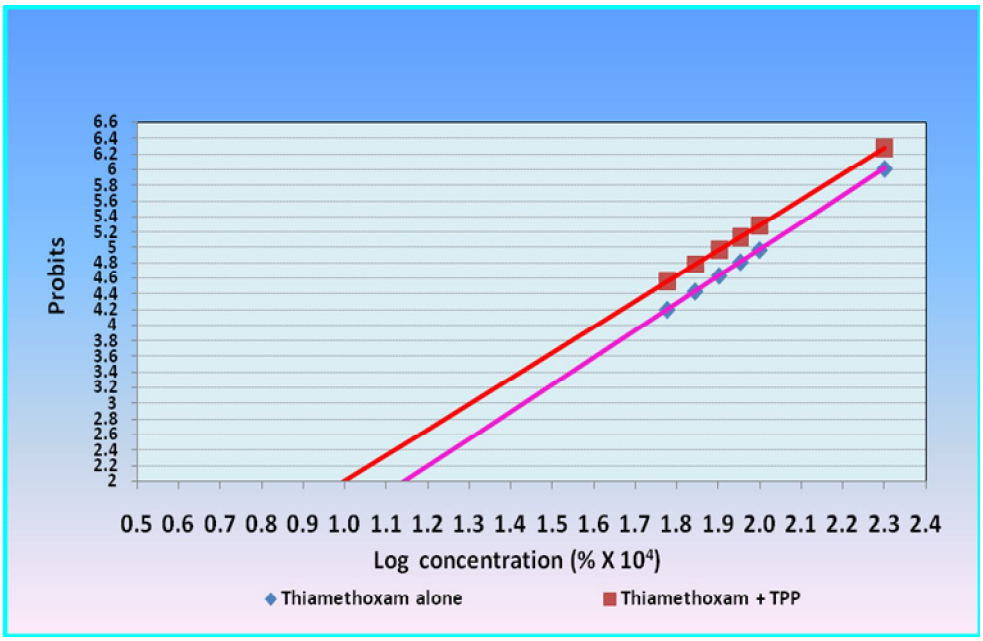


Fig. 4.48. Log concentration probit lines of West Godavari population of *N. lugens* to thiamethoxam and thiamethoxam + TPP (2009-10)

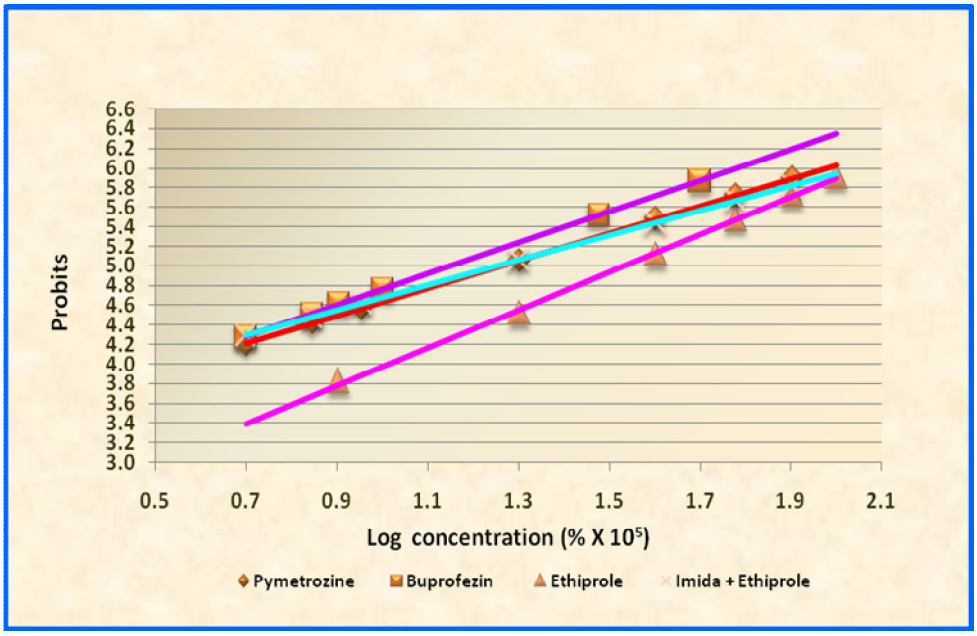


Fig. 4.49. Log concentration probit lines of certain novel insecticides for the management of resistant population of *N. lugens* (2008-09)

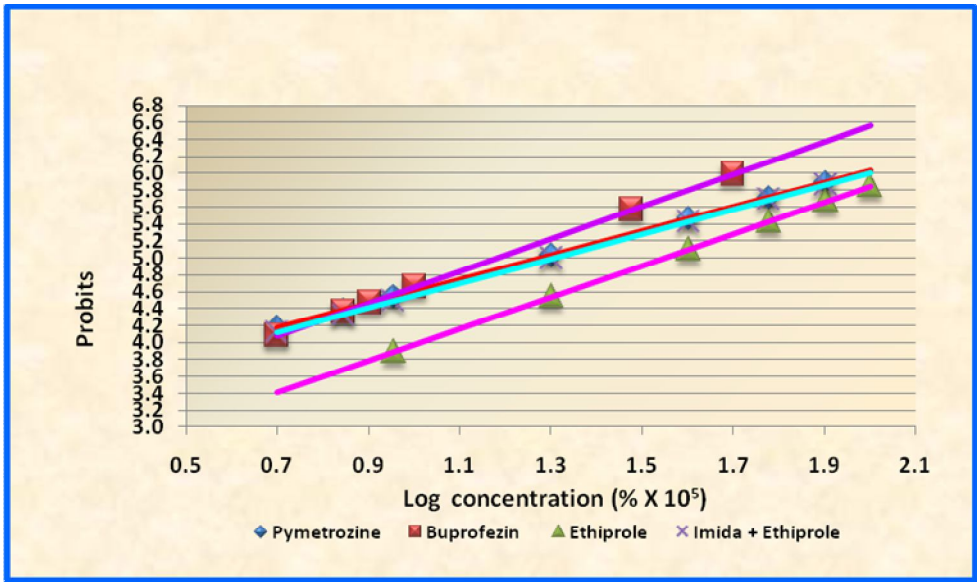


Fig. 4.50. Log concentration probit lines of certain novel insecticides for the management of resistant population of *N. lugens* (2009-10)

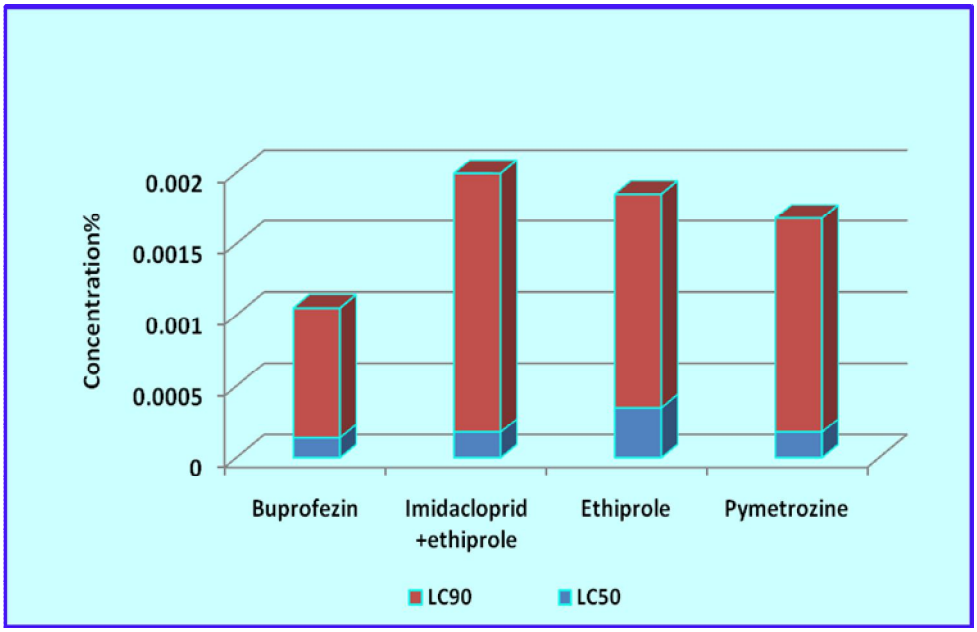


Fig. 4.51. Relative toxicity of novel insecticides against resistant population of *N. lugens* (2008-09)

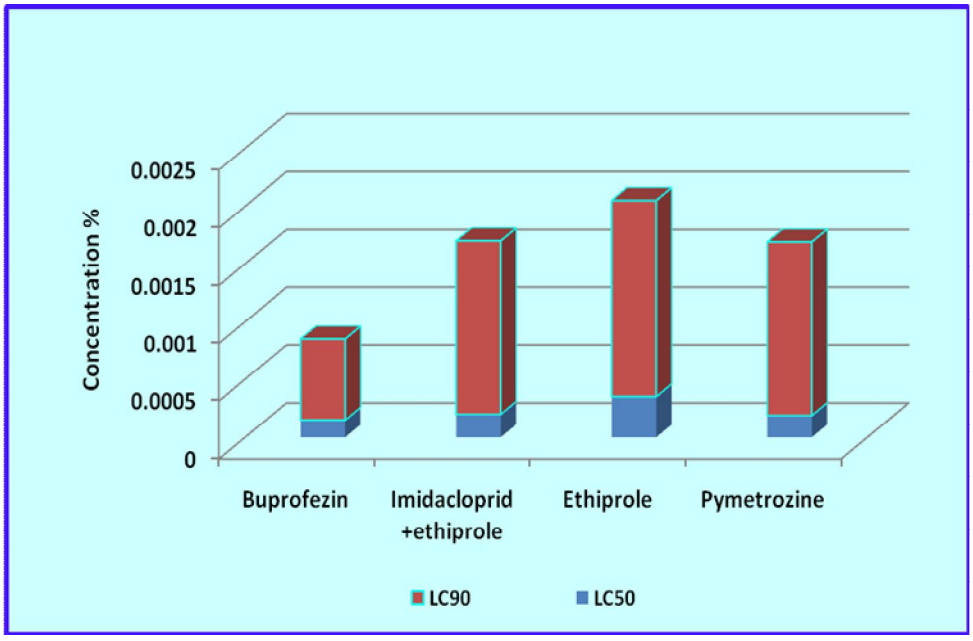


Fig. 4.52. Relative toxicity of novel insecticides against resistant population of *N. lugens* (2009-10)

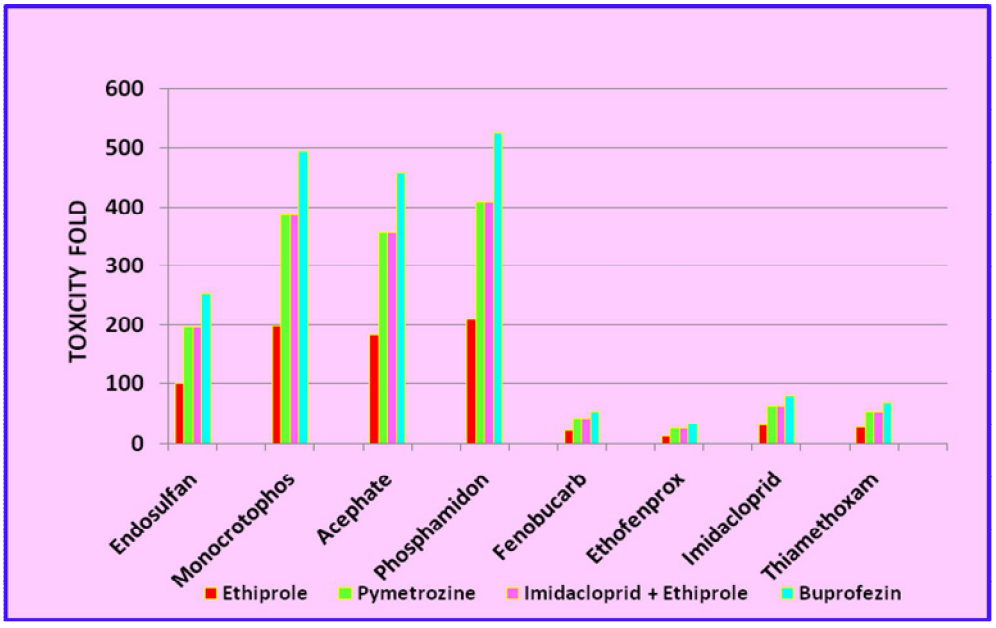


Fig. 4.53. Relative toxicity of novel insecticides in comparison with conventional insecticides against resistant population of *N. lugens* at LC_{50} (2008-09)

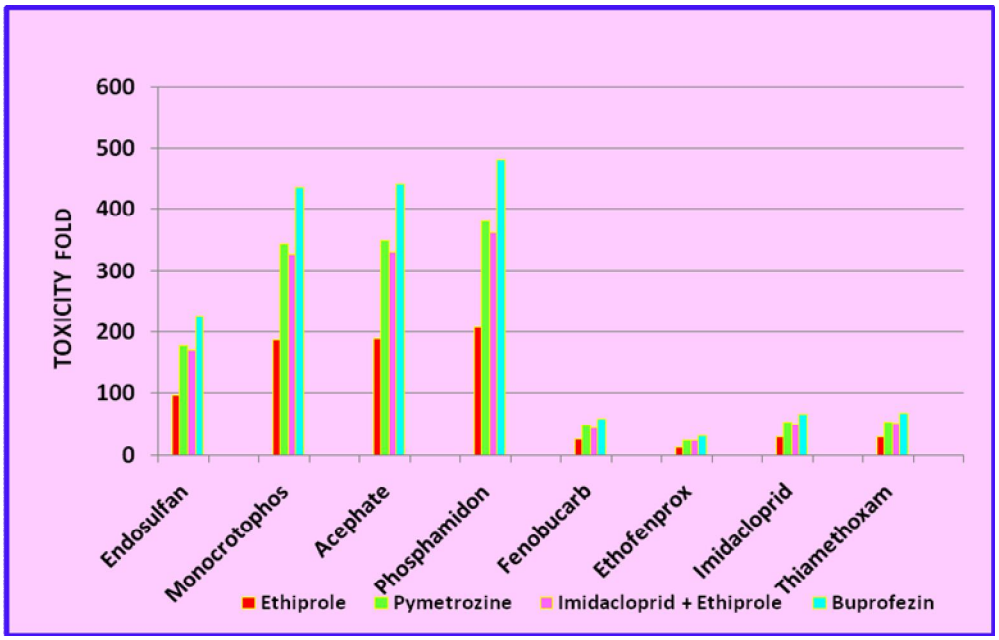


Fig. 4.54. Relative toxicity of novel insecticides in comparison with conventional insecticides against resistant population of *N. lugens* at LC_{50} (2009-10)

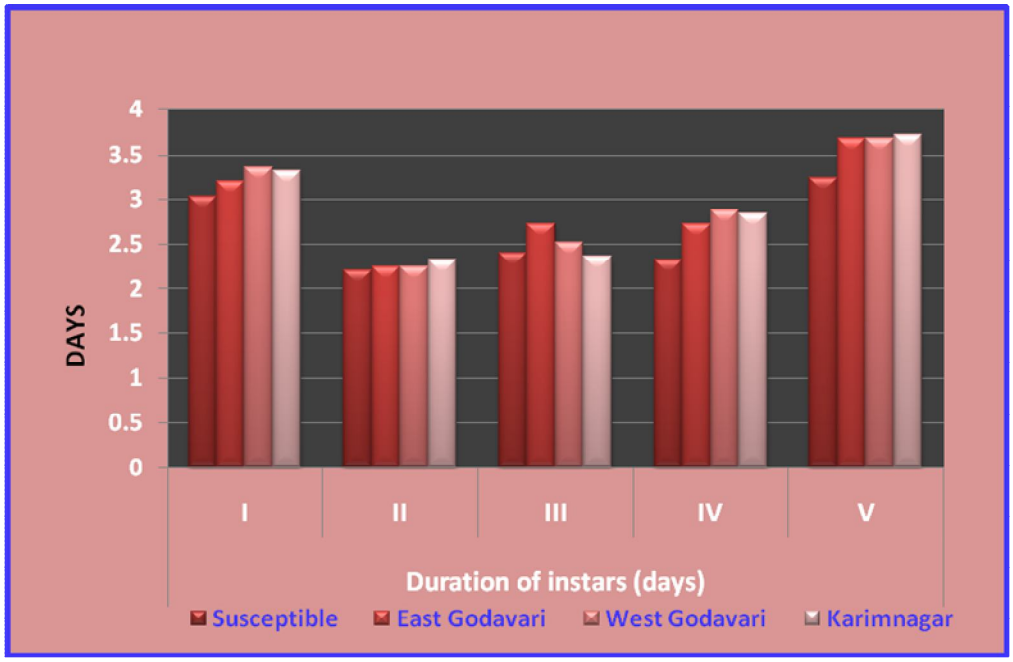


Fig. 4.55. Duration of nymphal instars of different populations of *N. lugens* (2008-09)

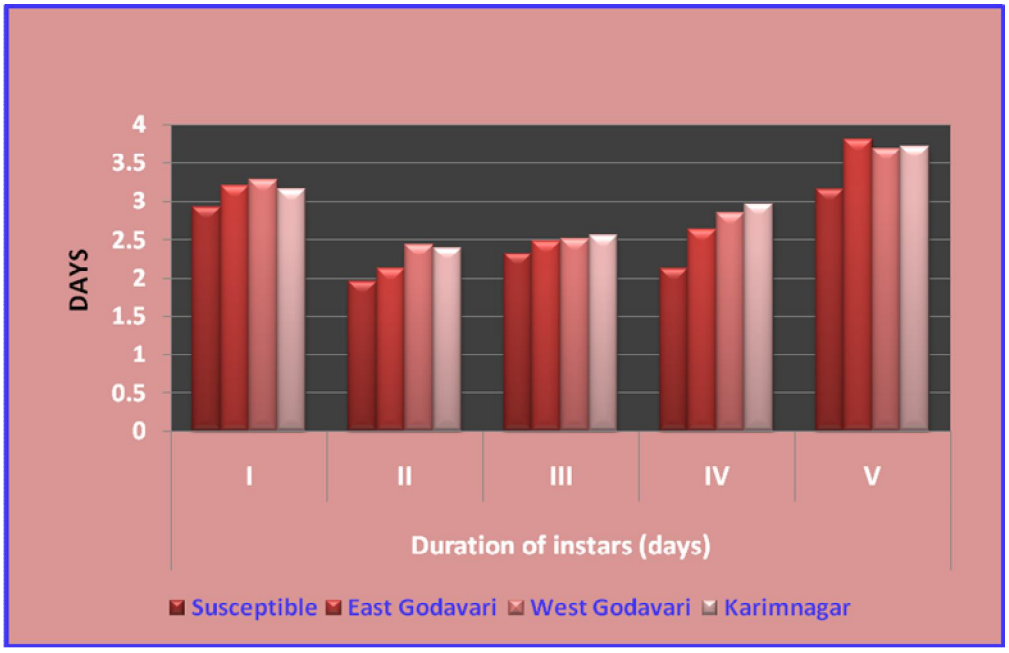


Fig. 4.56. Duration of nymphal instars of different populations of *N. lugens* (2009-10)

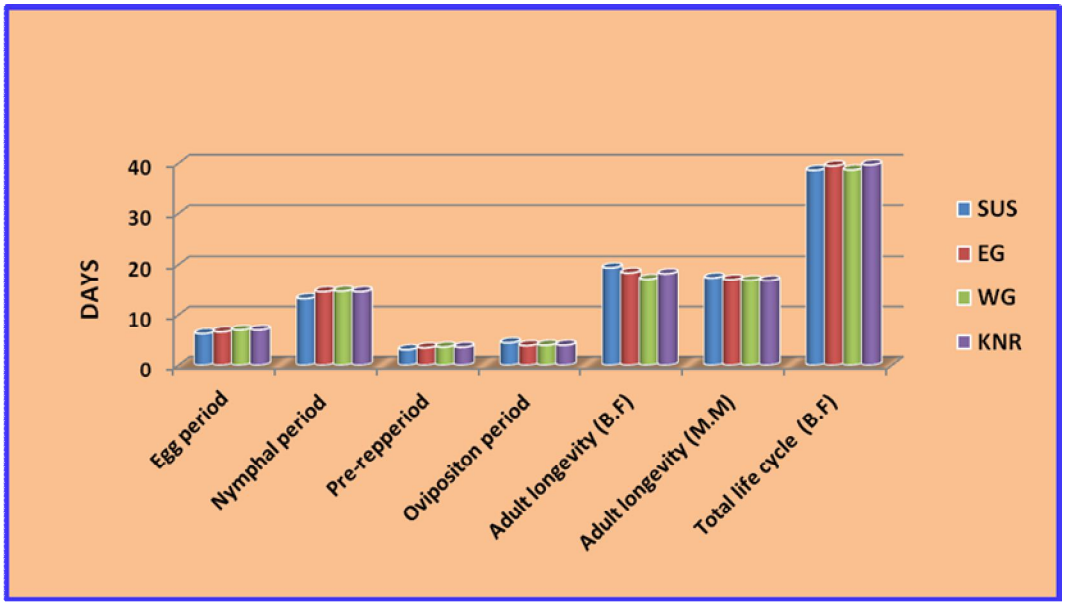


Fig. 4.57. Biological parameters of different populations of *N. lugens* (2008-09)

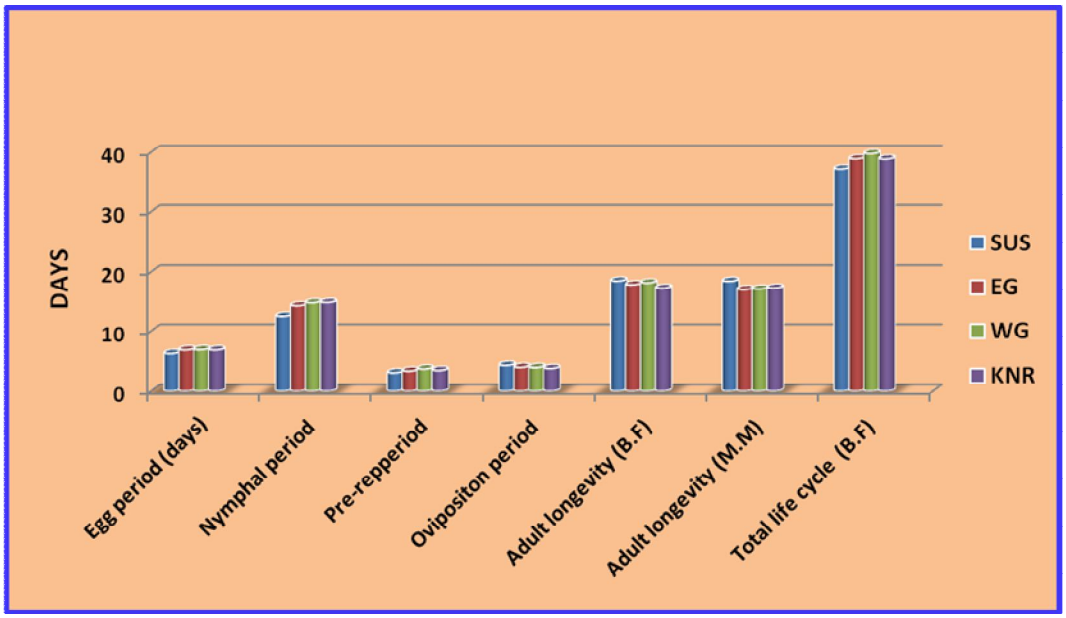


Fig. 4.58. Biological parameters of different populations of *N. lugens* (2009-10)

Chapter V

SUMMARY AND CONCLUSIONS

The results of present "Studies on assessment and management of insecticide resistance in rice brown planthopper, *Nilaparvata lugens* (Stal)" are summarized and conclusions are drawn hereunder.

The experiments were conducted in the laboratory of the Department of Entomology, Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru during 2008-09 and 2009-10 to determine the level of resistance acquired by *N. lugens* of West Godavari, East Godavari and Karimnagar districts to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam, to study the effect of synergists *viz.*, piperonyl butoxide (PBO) and triphenyl phosphate (TPP) against the test insecticides on resistant West Godavari strain of *N. lugens*, to manage the resistant strain of West Godavari district with novel insecticides *viz.*, buprofezin, pymetrozine, imidacloprid+ethiprole and ethiprole against nymphs of BPH and to study the influence of insecticide resistance on the biology of different populations.

The BPH populations of the three districts differed in the degree of resistance acquired by them to each of the eight test insecticides. The West Godavari strain of *N. lugens* was found to be 3.63 and 3.16; 3.01 and 3.07; 2.80 and 2.79; 2.22 and 2.30; 1.39 and 1.69; 1.50 and 1.36; 46.66 and 47.14; 13.11 and 12.94 folds resistant at LC_{50} and 2.60 and 2.52; 1.31 and 1.49; 1.10 and 1.28; 1.40 and 1.40; 1.06 and 1.50; 1.23 and 1.11; 9.4 and 14.66; 2.84 and 2.51 folds resistance at LC_{90} to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam during 2008-09 and 2009-10, respectively compared to susceptible strain.

The East Godavari strain of *N. lugens* acquired 3.53 and 3.02; 2.37 and 2.50; 2.42 and 2.36; 1.98 and 2.04; 1.41 and 1.44; 1.40 and 1.15; 28.75 and 34.76; 8.51 and 7.82 fold resistance at LC_{50} and 2.87 and 2.66; 1.07 and 1.31; 0.00 and 1.19; 1.35 and 1.38; 1.12 and 1.26; 1.27 and 1.02; 6.25 and 8.38; 3.73 and 4.05 fold resistance at LC_{90} to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam during 2008-09 and 2009-10, respectively compared to susceptible strain.

The Karimnagar strain of *N. lugens* showed 2.11 and 2.00; 2.34 and 2.52; 0.00 and 1.31; 1.93 and 2.12; 1.28 and 1.33; 1.10 and 1.03; 36.66 and 41.90; 12.70 and 11.41 fold resistance at LC_{50} and 1.26 and 1.25; 1.08 and 1.31; 0.00 and 0.00; 1.51 and 1.53; 1.06 and 1.30; 1.01 and 0.00; 8.05 and 13.38; 2.70 and 1.98 fold resistance at LC_{90} to endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam during 2008-09 and 2009-10, respectively compared to susceptible strain.

The synergistic effect of PBO with the test insecticides *viz.*, endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam revealed that the relatively resistant West Godavari strain of *N. lugens* recorded the synergistic ratios of 10.08 and 9.66; 19.83 and 11.43; 18.82 and 13.45; 15.95 and 11.52; 2.41 and 1.55; 3.75 and 1.37; 3.2 and 6.19; 3.46 and 1.97 at LC_{50} and LC_{90} levels, respectively during 2008-09. The corresponding synergistic ratios during 2009-10 were 8.48 and 11.42; 19.81 and 10.91; 21.35 and 17.20; 15.69 and 9.92; 2.44 and 1.73; 3.21 and 1.88; 2.67 and 5.89; 3.48 and 1.98 at LC_{50} and LC_{90} levels, respectively. The levels of resistance to acephate, monocrotophos and endosulfan could be brought down successfully with the synergist PBO. The results also indicated the active role of mixed function oxidases than esterases in the detoxification of test insecticides.

The synergistic effect of TPP with the test insecticides *viz.*, endosulfan, monocrotophos, acephate, phosphamidon, fenobucarb, ethofenprox, imidacloprid and thiamethoxam revealed that the relatively resistant West Godavari strain of *N. lugens* recorded the synergistic ratios of 6.66 and 7.41; 16.13 and 10.62; 14.22 and 11.60; 1.28 and 1.14; 1.59 and 1.33; 1.80 and 1.65; 1.09 and 1.12; 1.03 and 1.03 at LC_{50} and LC_{90} levels, respectively during 2008-09. The corresponding synergistic ratios during 2009-10 were 6.16 and 8.61; 14.2 and 9.75; 12.49 and 12.94; 1.29 and 1.22; 1.72 and 1.51; 1.95 and 1.34; 1.08 and 1.21; 1.24 and 1.19 at LC_{50} and LC_{90} levels, respectively. The synergism with TPP was more in monocrotophos followed by acephate, endosulfan, ethofenprox, fenobucarb, phosphamidon, imidacloprid and thiamethoxam,

Among the new insecticides, buprofezin was found to be the best alternative novel insecticide for managing the resistant strain followed by pymetrozine and imidacloprid+ethiprole and ethiprole alone.

The BPH populations of different districts recorded significantly more egg periods compared to the susceptible population. But no significant differences were observed in number of progeny, total nymphal periods, adult longevity, pre oviposition periods, oviposition periods and total life cycles.

The following conclusions were drawn from the results of the present investigations conducted.

- ✓ The BPH population of West Godavari district was relatively more resistant than East Godavari and Karimnagar populations.
- ✓ The different populations developed medium to high level of resistance to neonicotinoids and low level of resistance to endosulfan, monocrotophos, acephate, phosphamidon, ethofenprox and fenobucarb.
- ✓ The synergistic studies with PBO and TPP on resistant *N. lugens* populations of West Godavari district confirmed existence of low to moderate level of suppressible metabolic resistance.
- ✓ The synergism with PBO was more in acephate, monocrotophos and endosulfan, phosphamidon and less with ethofenprox, imidacloprid and fenobucarb.
- ✓ The levels of resistance to acephate, monocrotophos and endosulfan could be brought down with the synergists PBO and TPP.
- ✓ The synergism with TPP was observed more in monocrotophos followed by acephate, endosulfan, ethofenprox, fenobucarb, phosphamidon, imidacloprid and thiamethoxam.
- ✓ TPP showed no synergism with imidacloprid and thiamethoxam.
- ✓ Buprofezin, pymetrozine and imidacloprid+ethiprole proved to be toxic to the resistant West Godavari population of *N. lugens.*
- ✓ The relatively resistant BPH population of West Godavari strain recorded longer egg duration compared to susceptible population.
- ✓ The biological parameters *viz*., total nymphal period, number of progeny, adult longevity, pre oviposition period, oviposition period and total life cycle were not influenced by the degree of insecticide resistance.

Future line of Work:

- ✓ Baseline susceptibility data for all new molecules may be worked out for future reference.
- ✓ Impact of addition of new synergists on resistance levels may be worked out.
- ✓ Mechanisms of resistance operating in BPH may be worked out by following gel electrophoresis band patterns and enzyme assays.
- ✓ Field evaluation of effective molecules may be undertaken.
- ✓ Attempts should be intensified to generate more information on basic biochemical mechanisms of neonicotinoid resistance.

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