STUDIES ON INSECTICIDE RESISTANCE IN EARLY SEASON SUCKING PESTS OF COTTON IN TAMIL NADU

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON INSECTICIDE RESISTANCE IN EARLY SEASON SUCKING PESTS OF COTTON IN TAMIL NADU"** submitted in part fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENTOMOLOGY** to the Tamil Nadu Agricultural University, Coimbatore is a *record of bonafide* research work carried out by **Mr. P. M. PRAVEEN,** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABSTRACT

STUDIES ON INSECTICIDE RESISTANCE IN EARLY SEASON SUCKING PESTS OF COTTON IN TAMIL NADU

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The acute toxicity of six different insecticides *viz.*, thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate was assessed to the major early season pests of cotton *viz.*, *Aphis gossypii* Glover, *Amrasca devastans* Distant and *Thrips tabaci* Lind. in terms of LC_{50} and LC_{95}. The resistance in *A. gossypii*, *A. devastans*, and *Bemisia tabaci* Gennadius to different insecticides was monitored using discriminating dose screens in Coimbatore population at fortnightly intervals and one time in other locations.

The median lethal concentration to Coimbatore (TNAU) population of *A. gossypii* was 1.0414, 1.8055, 3.7057, 10.6924, 49.2606 and 5.3284 ppm for thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate respectively; the LC_{95} values being 35.2153, 43.4310, 139.4943, 629.6511, 1174.627 and 130.489 ppm respectively. The susceptibility increased after seven generations of insecticide exposure free culturing as evident from decline in LC_{50} and LC_{95} values to all the insecticides. Among the chemicals thiamethoxam and imidacloprid were found to be highly toxic.

The variation in susceptibility to different insecticides was high at LC_{95}; the susceptibility index (SI) varied between 2.42 and 12.81. The number of generations required for 10 fold decrease at LC_{50} varied from 11.75 (imidacloprid) to 12.72 (dimethoate).

The susceptibility of *A. gossypii* varied with the locations as well with chemistries as indicated from LC_{95}; it varied from 7.8824 to 40.5397 ppm for thiamethoxam, 9.5245 to 49.5397 ppm for imidacloprid, 37.4237 to 188.2971 ppm for monocrotophos, 57.4144 to 776.6293 ppm for dimethoate, 222.3473 to 3062.8740 ppm for methyl demeton and from 36.0650 to 176.2598 ppm for acephate. Kumbakonam population was highly susceptible irrespective of the chemicals tested whereas Dharapuram and Vellore populations were less susceptible.

The LC_{50} and LC_{95} values to Coimbatore population of *A. devastans* declined with the succeeding four generations. The LC_{50} values declined from 0.00087 to 0.00045 ppm for thiamethoxam; 0.00101 to 0.00052 ppm for imidacloprid and from 0.08013 to 0.05818 ppm for monocrotophos and LC_{95} values declined from 0.06721 to 0.00825 ppm; 0.08861 to 0.08330 ppm and from 0.62985 to 0.54695 ppm respectively. The order of toxicity was thiamethoxam > imidacloprid > monocrotophos. Wide variation was observed in SI at LC_{95}; it was low for monocrotophos (1.15) and high for imidacloprid (10.64). The number of generations required for 10 fold decrease at LC_{50} was 13.97, 13.87 and 28.82 for thiamethoxam, imidacloprid and monocrotophos respectively.

The variation was observed in both LC_{50} and LC_{95} values among the populations for the insecticides tested; the LC_{95} values ranged between 0.01850 and 0.08814 ppm for thiamethoxam, 0.02995 and 0.11855 ppm for imidacloprid, 0.4705 and 0.9513 ppm for monocrotophos, 1172.4990 and 4971.6380 ppm for dimethoate, 537.2525 and 6553.7100 ppm for methyl demeton and between 1293.6600 and 5368.7890 ppm for acephate. Kumbakonam population was highly susceptible for all the chemistries whereas

Dharapuram and Vellore populations exhibited less susceptibility. High resistance ratios were observed for Dharapuram and Vellore populations and low for Aduthurai and Vaigaidam populations.

The acute toxicity of three insecticides tested for *T. tabaci* collected from eight locations of Tamil Nadu showed variation in LC_{50} and LC_{95} values among the populations. The Kumbakonam population was highly susceptible as indicated from the lowest LC_{50} and LC_{95} values; 0.0571 and 1.1446 ppm for thiamethoxam; 0.0390 and 0.6914 ppm for imidacloprid and 94.1882 and 999.0683 ppm for dimethoate respectively. Dharapuram population was less susceptible; the LC_{50} and LC_{95} values being 0.0971 and 2.6076 ppm for thiamethoxam; 0.0713 and 1.965 ppm for imidacloprid and 171.5809 and 2986.3940 ppm for dimethoate respectively. The order of toxicity was imidacloprid > thiamethoxam > dimethoate irrespective of the locations.

The tentative discriminating doses (ppm) for monitoring insecticide resistance were fixed for six different insecticides viz., thiamethoxam (10), imidacloprid (10), monocrotophos (20), dimethoate (50), methyl demeton (220) and acephate (40) for *A. gossypii* and thiamethoxam (0.008), imidacloprid (0.008) and monocrotophos (0.55) for *A. devastans* based on the susceptible population of Coimbatore and Kumbakonam.

Monitoring insecticide resistance in Coimbatore population of *A. gossypii* from October 2002 to April 2003 revealed that the per cent survival varied from 10.42 to 19.00 for thiamethoxam; from 10.42 to 17.00 for imidacloprid; from 11.43 to 20.62 for monocrotophos; from 5.63 to 25.26 for dimethoate; from 13.54 to 20.00 for methyl demeton; from 13.04 to 21.43 for acephate. The populations of Dharapuram and Vellore recorded higher per cent survival to almost all the chemicals tested whereas the Kumbakonam population was found to be highly susceptible.

Insecticide resistance in Coimbatore population of *A. devastans* during October 2002 to April 2003 varied between 14.29 and 21.98 per cent for dimethoate; 13.48 and 20.41 per cent for methyl demeton; 12.90 and 18.75 per cent for acephate. The populations from Vellore and Srivilliputtur recorded higher per cent survival and the Kumbakonam population recorded lower per cent survival to all the insecticides tested.

The resistance level in Coimbatore population of *B. tabaci* varied from 14.00 to 18.67 for thiamethoxam; 13.00 to 20.00 for imidacloprid; 18.67 to 28.00 for monocrotophos; 18.67 to 26.00 for acephate; 26.00 and 34.00 for triazophos; 28.00 to 35.00 for cypermethrin; 20.00 to 28.00 for endosulfan. Among the populations the populations from Vellore, Dharapuram and Trichy locations recorded higher rate of survival. The Kumbakonam population was found to be highly susceptible to all the chemistries tested recording less than 15 per cent survival.

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CHAPTER I
INTRODUCTION

Cotton is attacked by several insect pests causing drastic reduction in yield. Out of 1326 insects and mites recorded all over the world (Hargreaves, 1948), 200 insect species are associated with cotton in India. Among these 12 are responsible for 60-70 per cent yield losses (Anonymous, 1981). Sucking pests have become quite serious from seedling stage, their heavy infestation at times reduces the crop yield to great extent (Dhawan *et al.*, 1988). The estimated loss is upto 21.2% (Rote *et al.*, 1983; Patil, 1998; Dhawan and Sidhu, 1986). Among the sap feeders aphid, *Aphis gossypii* Glover, leaf hopper, *Amrasca devastans* Distant, whitefly, *Bemisia tabaci* Gennadius and thrips, *Thrips tabaci* Lind. are important. The damage is more severe in the early stages of crop growth and can affect the crop stand and yield of cotton.

Cotton growers in India depend heavily on synthetic pesticides to combat these sucking pests; atleast 2-3 sprays are directed against sucking pests (Nagia *et al.*, 1989; Lingappa *et al.*, 2001; Anonymous, 1999).

Due to the continuous and indiscriminate use of these systemic insecticides, their efficacy is lost due to buildup of resistance to these insecticides due to selection pressure (Regupathy, 1999).

During the last few decades, insect species have acquired resistance to insecticides. Insecticide resistance had been reported in over 500 arthropod species (Georghiou, 1990). Field control failures though may indicate the development of resistance, they might also be due to other causes like improper application techniques and use of spurious materials. Hence, monitoring of insecticide resistance is needed to abate the development of insecticide resistance.

The objective in resistance monitoring is to exaggerate the differences between susceptible and resistant individuals such that frequency of misclassification is greatly reduced (ffrench-constant and Roush, 1990). For estimating resistance level in a population, the initial base-line level of susceptibility is essential so that, comparisons can be made in future (Hopkins *et al.*, 1984). For successful monitoring programme the base-line susceptibility to different insecticides must be estimated separately for each species in the complex. The laboratory population which has not undergone any exposure to insecticides provides the advantages of totally susceptible bench mark for calculating resistance ratios. Resistance in insect pests can be detected by the use of discriminating dose tests. Such detection should be done at the earliest stage of effective pest management. Hence, a suitable monitoring technique is to be developed not only to detect the presence of resistance but also to monitor the changes in resistance frequency to determine whether a programme is effective or not.

The reports on the development of resistance in sucking pests of cotton are very limited in India except that, for whitefly (Regupathy *et al.*, 1998) and leafhopper (Jeyapradeepa and Regupathy, 2002). Resistance in *A. gossypii* was not reported from India so far. Resistance was reported in *A. devastans* (Chalam and Subbaratnam, 1999; Jeyapradeepa and Regupathy, 2002), *B. tabaci* (Prabhaker *et al.*, 1985; Pandurangadu and Raju, 1990; Singh *et al.*, 1998a; Chinnabbai *et al.*, 2001; Kranthi *et al.*, 2001; Balakrishnan *et al.*, 2002) and *Scirtothrips dorsalis* Hood (Sridhar and Jhansi Rani, 2003) in certain parts of India. Jeyapradeepa and Regupathy (2002) generated base-line for *A. devastans* to certain commonly used insecticides in the cotton growing areas of Tamil Nadu and moderate resistance was reported in certain locations of Tamil Nadu. No other systematic work on developing discriminating doses and monitoring resistance in Tamil Nadu was done for sucking pests of cotton, as being done in *A. devastans* (Jeyapradeepa and Regupathy, 2002), *Helicoverpa armigera* (Hub.) (Armes *et al.*, 1992a;

Pasupathy and Regupathy, 1993; Regupathy, *et al.,* 1994 and 1998), *Plutella xylostella* (Linn.) (Chandrasekaran and Regupathy, 1996; Renuka and Regupathy, 1996) and *Spodoptera litura* (Fab.) (Niranjan Kumar and Regupathy, 2000).

Keeping these in view, the present study was undertaken with following objectives:

1. To create baseline data for a few widely used insecticides for the control of *A. gossypii* and for new chemistries used against *A. devastans* for fixing discriminating dose.
2. To study the acute toxicity of certain insecticides to *A. gossypii*, *A. devastans* and *T. tabaci* collected from different locations of Tamil Nadu and
3. To monitor the insecticide resistance in *A. gossypii*, *A. devastans* and *B. tabaci* collected from different locations of Tamil Nadu by discriminating dose technique.

CHAPTER II
REVIEW OF LITERATURE

The review of the literature on bioefficacy of insecticides, monitoring methods, insecticide resistance and mechanism of insecticide resistance for *A. gossypii*, *A. devastans*, *B. tabaci* and *T. tabaci* is presented in this chapter.

2.1. Susceptibility of sucking pests to insecticides

An array of insecticides had been evaluated for their bioefficacy and the insecticides found effective against sucking pests are presented in Tables 1 - 4.

2.2. Monitoring methods

2.2.1. Topical assay

It is an old and reliable method. Technical grade insecticide dissolved in less toxic carrier/solvent (acetone) was applied topically (usually 0.5 μl) to the dorsal thoracic segments of the test insect with the help of a microapplicator and transferred to petridishes provided with feed. Mortality was assessed after 24h. Control insects were treated with acetone alone.

Based on international collaborative study by the FAO panel of experts on pest resistance to pesticides and crop loss assessment, this method was recommended as FAO method No. 21 (1979) for generating baseline data for monitoring insecticide resistance in leaf and plant hoppers of rice viz., green leafhopper, *Nephottetix cincticeps* Uhler (Kao *et al.*, 1982), brown planthopper, *Nilaparvata lugens* Stal. (Sujatha, 1994; Sarupa *et al.*, 1999) and white backed planthopper, *Sogatella furcifera* Horvath (Hirai, 1994).This method was also followed for aphid, *Myzus persicae* (Sulzer) (Barber *et al.*, 1999; Wu Jinquan, 1997), *A. gossypii* (Cheng Guilin *et al.*, 1997; Jiang Yanchao *et al.*, 2002) and greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Zheng Bingzong and Rui, 1992).

2.2.2. Leaf residue / Leaf disc bioassay

The leaf discs of 3-5 cm diameter were washed thoroughly and dipped in the test solutions for fifteen seconds with gentle agitation. They were allowed to surface – dry on a paper towel and then placed in petridishes containing moistened filter papers to avoid desiccation of leaves. Test adults were briefly immobilized with carbon dioxide and transferred to the leaf discs in petridishes by tapping lightly. The mortality was recorded 24, 48 and 72h after the treatment. This method was followed for *A. devastans* by Sabitha and Sosamma Jacob (1995) and Ahmed *et al.* (1999) as well as for other sap feeders like cotton whitefly, *B. tabaci* (Dittrich *et al.*, 1990; Cahill *et al.*, 1996a), brinjal aphid, *M. persicae* (Ambrose and Regupathy, 1990), cotton aphid, *A. gossypii* (O'Brien *et al.*, 1992) and apple aphids, *Aphis citricola* Van der Goot and *Myzus malisuctus* Matsumara (Cho *et al.*, 1997).

2.2.3. Foliar application

Seedlings of 20-25 cm tall with four true leaves were dipped for twenty seconds in the required concentration of test solutions or in deionized water (control). The treated seedlings were then allowed to air dry for 3h. Test insects were confined to treated cotton seedlings with leaf clip-on cages (Melamed Majdar *et al.*, 1984) and kept under controlled room conditions of 26 + 1^{o}C, 60 per cent RH for 48h. This was followed for *B. tabaci* (Prabhakar *et al.*, 1989; Horowitz and Ishaaya, 1992), *T. vaporariorum* (Omer *et al.*, 1992), *B. tabaci* (Horowitz *et al.*, 1998) and *A. gossypii* (Grafton – Cardwell, 1991).

2.2.4. Thin layer exposure bioassay / Surface residue vial bioassay

In this method, the test insects were exposed to films of insecticides which were applied to the inner surfaces of glass scintillation vials of 3.5 ml capacity. Mortality was recorded 8h after treatment. Shotkoski *et al.* (1990) used this method to assess the development of resistance by continuous exposure of sorghum greenbug, *Schizaphis graminum* Rond. to the systemic insecticides aldicarb, carbofuran, disulfotan and tebufos. Archer *et al.* (1994) and Rider *et al.* (1994) used this method for resistance monitoring.

2.2.5. Sticky card technique

Desired insecticide-sticker concentration was stirred first for 1 min. with a glass pasteur pipette. An aliquot of 0.35 – 0.37 ml of the mixture was placed uniformly on a yellow ring card (8 x 8cm, 10 x 10cm) and spread evenly over 6 x 6 cm area with the edge of a glass microscope slide to obtain a very thin layer of the mixture on the card. It was allowed for 1-2h to permit solvent evaporation. Test insects were blown out of the aspirator onto the card and the card was placed into a half litre plastic ice cream container provisioned with water saturated cotton to maintain high relative humidity and sealed with a lid. The lid was then placed in an incubator at 21^{o}C and a photo period of 14:10 (L:D). After 24h, mortality was evaluated under a stereomicroscope by gently prodding each insect and looking for any motion of body parts. Sanderson and Roush (1992) used this technique for *T. vaporariorum.*

2.2.6. Slide dip bioassay

Wooden applicator sticks were used to apply ten small cones of clear silicone glue to strips of two-sided transparent tape attached to microscope slides. Test insects were placed venter side up on the wet silicone glue with a small camel hair brush. After the insects were glued to a slide, the slide was held horizontally and 2ml of insecticide was pipetted onto the insects and allowed to pool on the slide.

Microscope slides containing aphids were hung vertically by binder clips to dry at room temperature. Responses of aphids were measured 2h after exposure. Kerns and Gaylor (1992) used this bioassay for *A. gossypii.*

2.2.7. Spray method

In this method, the test insects were sprayed with 2 ml of insecticide using Potter's tower at a pressure of 340 g/cm^2 and allowed to dry for five minutes. The treated insects were then transferred to a clean container provided with untreated food and the mortality was assessed after 24 (Lin *et al.*, 1979) and 48h (Dhingra and Seema, 1998). This was followed for *A. devastans* (Sabitha and Sosamma Jacob, 1995), green leafhopper, *N. cincticeps* (Lin *et al.*, 1979) and brown plant hopper (Dai and Sun, 1984; Rao and Rao, 1980).

2.2.8. Glass vial technique

Desired chemical residues were achieved by pipetting 225 μl of acetone into each vial, and by rotating the vial until the acetone evaporated, leaving the residue evenly distributed on the interior. Twenty to thirty (unsexed) adults were mouth-aspirated and transferred to the treated vials. The vials were capped and held at 20±2^{o}C for 3h before taking mortality readings. This technique was adopted for silverleaf whitefly, *Bemisia argentifolia* Bellows & Perring by Plapp *et al.* (1987) and Sivasupramanian and Watson (2000).

2.2.9. Filter paper method

The method was used against whiteflies by Balakrishnan *et al.* (2002). Whatman No.1 filter paper was cut into rectangular bits (size suitable to the specimen tubes) and each of these bits was saturated with the test insecticidal solution and allowed it to dry for few minutes. Then, the impregnated filter paper bit was inserted into the specimen tube of 25 ml capacity as an innerlining. A bit of cotton leaf with intact petiole from untreated cotton plants was inserted into the specimen tube to avoid starvation of whiteflies. The cut end of petiole projecting out of the specimen tube was covered with a cotton swab soaked in water to maintain turgidity of the leaf. The adult whiteflies were carefully transferred to each of the specimen tubes containing insecticide impregnated filter paper at the rate of 20 insects per tube. The open end of the specimen tube was closed with a cotton stopper. The mortality of whiteflies was recorded 24h after treatment.

2.3. Insecticide resistance

2.3.1. Aphid

Development of insecticide resistance was reported atleast in 20 species of aphid (Georghiou, 1981). Resistance to organophosphates in *A. gossypii* was first reported in 1964 (Kung *et al.*, 1964). Subsequently, resistance to carbamates (Furk *et al.*, 1980) and pyrethroids (Zil'bermints and Zhuravleva, 1984) was reported.

In the early 1980s, pyrethroids replaced the organophosphate insecticides for aphid control. By 1986, the aphids evolved resistance to the pyrethroids with levels reported as high as 126.6 fold for deltamethrin and 412.4 fold for fenvalerate (Wei *et al.*, 1988).

The results of a four year systematic monitoring of pyrethroid resistance since 1983 in melon-cotton aphid, *A. gossypii* using the insects collected from Beijing suburbs and Northern region of Hebei Province, revealed a high level of resistance to fenvalerate and deltamethrin. The highest rank of the resistance on the tested colonies were 519.7 and 6416 to fenvalerate and 401.2 and 2404.1 fold to deltamethrin based on the results of LC_{50} and on LC_{95} respectively in 1986 (Zheng Bingzong *et al.*, 1992).

A susceptible strain of *A. gossypii* was selected with methomyl, endosulfan, methamidophos and cypermethrin. Resistance increased rapidly to cypermethrin, quickly to methomyl, steadily to methamidophos and slowly to endosulfan by selection pressure through 16 generations. The level of resistance was high to cypermethrin and less to endosulfan (Zhang, 1996).

High level of resistance was detected in cotton aphids from Xinjang (766 fold) and Shandong (1,835 fold) during 1995-1996 (Cheng Guilin *et al.*, 1997). Turnip aphid, *Liphaphis erysimi* (Kaltenbach) from Beijing suburbs expressed high levels of resistance to all pesticides tested *viz.*, deltamethrin, fenvalerate, dimethoate and omethoate. The resistance levels were higher to the pyrethroids than organophosphates (Zheng Bingzong *et al.*, 1997).

The resistance of *A. gossypii* in North China to pyrethroids increased by 171 times in general, 3230 times in some cotton fields in 1985 (Sun *et al.*, 1994). Zhaojun (2002) reported that the resistant level of *A. gossypii* to deltamethrin was very high. The LD_{50} value for fundatrigenia of resistant strain was 12,000 times greater than that of sensitive strain.

Herron *et al.* (2000) reported that *A. gossypii* was resistant to endosulfan and pyrethroids but not to carbamates or organophosphates in Australia. Primicarb, organophosphate, endosulfan and pyrethroid resistance was identified in Western Australia in *A. gossypii*. The population displayed high to extreme resistance that was linked with control failure and have the potential to seriously impact on the cotton industry (Herron *et al.*, 2001).

Delorme e*t al.* (1997) reported that a strain (R) of *A. gossypii* from Southern France was found to be resistant to several insecticides particularly to primicarb as compared to a susceptible strain (S) and the highest resistance factor of 1350 was observed.

According to Deguine (1996) there had been a general development of resistance to most insecticides especially organophosphates in *A. gossypii* on cotton in Cameroon since 1993. In laboratory toxicity tests, clones of *A. gossypii* revealed resistance to monocrotophos and dimethoate.

Hollingsworth *et al.* (1994) tested 16 populations of *A. gossypii* from Hawai and reported 3.5, 390, 9.2 and > 2000 fold resistance to endosulfan, esfenvalerate, methomyl and oxydemeton methyl respectively.

Kerns and Gaylor (1992) found low levels of resistance to bifenthrin and cypermethrin in *A. gossypii* populations in Alabama and Texas regions.

Three strains of *A. gossypii* collected from cotton fields in the Sudan Gezira over three seasons (from 1988 to 1990) were highly resistant to the insecticides fenvalerate, deltamethrin, methidathion, dimethoate, primicarb, methomyl and endosulfan in laboratory tests (Gubran *et al.*, 1992).

2.3.2. Leafhopper

A. devastans collected from cotton fields from three locations in Tamil Nadu, indicated tolerance to methyl demeton, dimethoate, endosulfan, phosalone and phosphamidon (Santhini and Uthamasamy, 1997).

The consolidated report in insecticide resistance indicated the development of resistance in *A. devastans* for organophosphorous compounds (Rajmohan, 1998). Laboratory studies conducted by Chalam and Subbaratnam (1999) in respect of insecticide resistance acquired by the cotton leafhopper, *Amrasca biguttula biguttula* Ishida in Andra Pradesh, revealed that the hopper population had developed resistance to endosulfan, monocrotophos, cypermethrin and phosphamidon.

In the studies carried out by Jeyapradeepa (2000) for monitoring resistance in *A. devastans* in six different locations of Tamil Nadu, the mean resistance was 26.73 for dimethoate, 18.41 for methyl demeton and 19.48 per cent for Vaigaidam. Oddanchatram and Vaigaidam population exhibited a moderate level of resistance to dimethoate and methyl demeton. Oddanchatram and Aruppukottai population exhibited moderate level to acephate. Aruppukottai and Vikramangalam exhibited the moderate level of resistance to dimethoate. The Karuppayurani and Killikulam population are found to be susceptible to all the insecticides tested.

In Pakistan, Ahmed *et al.* (1999) reported the development of resistance to pyrethroids i.e. moderate to high resistance to zeta cypermethrin, high resistance to deltamethrin, low resistance to alpha cypermethrin, fenpropathrin, bifenthrin, lambdacyhalothrin and ethofenprox and a very low resistance to cypermethrin and deltamethrin.

2.3.3. Whitefly

In India, Pandurangadu and Raju (1990) reported that *B. tabaci* had developed resistance to many pesticides and thus it seemed certain that the resistance was one factor contributing to the upsurge of whiteflies in contiguous areas of northern India and probably to outbreaks in Gujarat on the north-west coast.

Prasad *et al.* (1993) tested *B. tabaci* populations collected from cotton fields in Guntur, Nellore and Srikakulam areas in Andhra Pradesh for their resistance against nine conventional insecticides. Guntur population of *B. tabaci* was 7.2, 5.9, 10.6, 4.8, 5.0, 6.1, 4.5, 1.9 and 4.0 times resistant and Nellore population 1.9, 1.6, 2.5, 2.3, 4.4, 3.2, 2.1, 1.2, and 2.7 times resistant to BHC, endosulfan, dimethoate, phosalone, acephate, monocrotophos, quinalphos, triazophos and carbaryl respectively. The whitefly populations from Prakasam, Kurnool and Krishna districts of Andhra Pradesh had developed resistance to endosulfan, monocrotophos, triazophos, acephate and cypermethrin (Chinnabbai *et al.*, 2001).

Sharma and Batra (1995) attributed development of resistance in *B. tabaci* to insecticides *viz.*, cartaphydrochloride, imidacloprid, ethion, spark, triazophos, methomyl, malathion, ethofenprox, fluvalinate, monocrotophos, endosulfan, decamethrin and methyl demeton as one of the reasons for flare up of whitefly in Haryana state.

B. tabaci, collected from fields in different regions of Punjab showed resistance to almost all the insecticide groups recommended for use on cotton crop in this state. Populations in the cotton belt possessed high level of resistance to cypermethrin, acephate, chlorpyriphos, phosphamidon, oxydemeton methyl and demeton, moderate level of resistance was also evident to monocrotophos, quinalphos, and deltamethrin (Singh *et al.*, 1998a).

B. tabaci field strains collected from 22 cotton growing districts across India exhibited resistance to methomyl and monocrotophos and susceptibility to triazophos (Kranthi *et al.*, 2001) and moderately high level of resistance to cypermethrin, but resistance to endosulfan and chlorpyriphos was negligible in the field strains tested (Kranthi *et al.*, 2002).

Zheng Bingzong and Rui (1992) reported that resistance level to fenvalerate and deltamethrin reached 405.6 and 1,941.7 fold respectively in *T. vaporariorum* based on the dipping bioassay recommended by FAO in 1988. However Zheng Bingzong and Gao Xiwu (2002) found that the resistant level towards the two pyrethroids declined in a stepwise manner, whereas resistance towards dimethoate and buprofezin began to ascend.

Wide spread resistance in *B. tabaci* to organophosphates, carbamates, pyrethroids and endosulfan and the use of previously synergistic OP/pyrethroid mixture appeared to be selecting for new or modified resistance mechanism. Resistance to promising insecticides introduced earlier for control of *B. tabaci* such as buprofezin, pyreproruten and imidacloprid had already been detected in localized areas (Cahill *et al.*, 1996b).

In the laboratory tests, Prabhaker *et al.* (1985) detected high resistance to sulprofos and parathion-methyl ranging from 20 to 54 fold developed in three field populations of *B. tabaci* collected from cotton in southern California as compared to susceptible strain. Moderate level of resistance (3 - 9 folds) to fenthion, malathion, and parathion were observed in a strain from Imperial Valley. In addition two strains showed relatively high level of resistance to permethrin (12-29) and resistance to DDT (6.5 to 9.5 folds) was present in all three strains.

Elbert and Nauen (1996) reported that whitefly populations from Almeria, Spain showed slight tolerance (2 to 5 fold) to imidacloprid compared to a reference laboratory strain in all bioassays used and the highest resistance factors were determined for endosulfan and monocrotophos. However, the field populations collected in 1994, 1996 and 1998 indicated an increase, albeit a slow one, in resistance to imidacloprid over this period. Comparative studies of other neonicotinoids using the same bioassay revealed a high degree of cross-resistance to acetamiprid and thiamethoxam. A high level of resistance to cyfluthrin, endosulfan, monocrotophos, methamidophos, and pymetrozine each at 200 mg litre^{-1} was observed (Elbert and Nauen, 2000). A high degree of resistance against several chemical classes of insecticides, including organophosphates, carbamates, pyrethroids, insect growth regulators and chlorinated hydrocarbons had been reported in Spain (Elbert and Nauen, 2000).

Dittrich and Ernst (1983) observed that Sudanese field strains of *B. tabaci* were highly resistant to dimethoate and monocrotophos, moderately resistant to dicrotophos and quinalphos and less resistant to cypermethrin.

Bashir (1999) reported less susceptibility of *B. tabaci* to endosulfan, amitraz, dimethoate, methomyl, dimethoate + endosulfan, amitraz + endosulfan, chlorfenvinphos, chlorfenvinphos + endosulfan, deltamethrin, deltamethrin + endosulfan, methomyl + endosulfan, endosulfan + chlorpyriphos and chlorpyriphos alone and none was able to reduce the pest population below the economic threshold limit of 600 adults/100 leaves in Sudan.

A very high resistance to dimethoate and deltamethrin, and a moderate resistance to monocrotophos during 1992-96 was observed and from 1997 to 2000, resistance to these insecticides dropped to low levels because of less reliance on them for whitefly control in Pakistan (Ahmed *et al.*, 2002).

2.3.4. Thrips

Morse and Brawner (1986) and Immaraju *et al.* (1989) observed that citrus thrips, *Scirtothrips citri* (Moulton) developed resistance to DDT, dimethoate, acephate, bendiocarb and formentanate. Immaraju *et al.* (1992) reported the development of resistance in four populations of *Frankliniella occidentalis* Pergande from Californian greenhouses to chlorpyriphos, methomyl, permethrin, bifenthrin and abamectin.

The populations of western flower thrips, *F. occidentalis* from greenhouses in California showed increased resistance level in the SB strain (intensive use of insecticide) than SD strain (minimal use) and UC strain (no pesticide) to dimethoate, fenpropathrin and methomyl (Robb *et al.*, 1995). Resistance to acephate, methiocarb and endosulfan was observed in three European and two African green house populations of *F. occidentalis* (Brodsgaard, 1994).

Zhao *et al.* (1995a) observed the development of resistance to imidacloprid in greenhouse population of *F. occidentalis* in Missouri.

Shelton *et al.* (2003) reported the development of resistance by onion thrips, *T. tabaci* to λ-cyhalothrin in some onion growing regions of New York.

2.4. Mechanism of insecticide resistance

2.4.1. Aphid

Resistance to a carbamate (aldicarb), an organochlorine (endosulfan), an organophosphate (chlorpyriphos) and a pyrethroid (bifenthrin) was documented in *A. gossypii* collected from cotton in Mississippi. Spectrophotometric analyses indicated significantly higher carboxylesterase activity in resistant aphids compared with susceptible aphids (O'Brien *et al.*, 1992).

Carboxylesterase activity of *A. gossypii* using naphtha-1-yl acetate as a substrate, varied greatly among the clones and was closely correlated to the degree of organophosphorous insecticides (Suzuki *et al.*, 1993).

Levels of resistance and acetylcholinesterase (AChE) sensitivity to primicarb and organophosphorus insecticides were examined in three clones of *A. gossypii* and in a non-clonal culture derived from a sexually reproducing population in China. Two insensitive AChE variants were identified with differing levels of insensitivity to these chemicals (Moores *et al.*, 1996). *A. gossypii* strains highly resistant to several anticholinesterase pesticides possessed an allele which modifies acetylcholinesterase and made it resistant to these pesticides (Villatte *et al.*, 1997).

Wu Jinquan (1997) observed that the resistance of peach-potato aphids, *M. persicae* to sumithion was caused by an increase in carboxylesterase activity. Zheng Bingzong *et al.* (1997) reported that mixed function oxidases (MFO) play an important role in aphid resistance to pyrethroids and organophosphates.

Electrophoretic quantitative and qualitative determination of variations in non-specific esterases and acetylcholinesterase sensitivity confirmed that there were two forms of mutant acetylcholinesterase that conferred resistance to primicarb. One of these was associated directly with resistance to demeton-S-methyl, while the other induced resistance only in combination with medium to high levels of non-specific esterase activity (Zhaojun *et al.*, 1998).

Zhaojun (2002) found that the knockdown resistance was the main mechanism for cotton aphid resistance to deltamethrin. Metabolic enzymes, esterases and MFO took some part in detoxification processes of deltamethrin, but they exhibited similar and equivalent roles both in resistant and sensitive strains.

Differences in the carboxylesterase band patterns were detected between organophosphate-susceptible and resistant clones and the overall enzyme activity determines the degree of resistance in *A. gossypii* (Saito and Hama, 2000)

2.4.2. Leafhopper

Four insecticides *viz.*, endosulfan, monocrotophos, phosphamidon, and cypermethrin, were synergized by piperonyl butoxide (PBO), indicating metabolic detoxification by mixed function oxidases (MFO). MFO played a predominant role in imparting resistance to cypermethrin and monocrotophos, which was indicated by high synergistic ratios. On the other hand, in endosulfan and phosphamidon, MFO acted as one of the mechanisms of resistance, which was evident in the low to moderate synergistic ratios in these cases (Chalam *et al.*, 2001).

2.4.3. Whitefly

Biochemical work reviewed by Byrne *et al.* (1992) indicated a general involvement of non specific esterases and insensitive acetylcholinesterase (AChE) in resistance to pyrethroids and organophosphates respectively.

Insecticide-sensitive and insensitive AChE variants in individual adults of *B. tabaci* were identified on the basis of their sensitivities to inhibition by the insecticides paraoxon and azamethiphos using a microplate assay. All populations of *B. tabaci*, including those from the UK, contained a large proportion of individuals with insensitive AChE capable of conferring extremely high resistance (Byrne and Devonshire, 1993).

Byrne *et al.* (1994) observed two acetylcholinesterase (AChE) variants differing in their sensitivity to inhibition by the organophosphorous insecticide paraoxon in a population of *B. tabaci* from cotton in Israel using a single insect kinetic microplate assay.

Selection for resistance to fenpropathrin was performed by exposing adults of two field collected populations of *B. tabaci* to increasing dosages of fenpropathrin for four generations. Samples of adults used for colorimetric measurements of esterase activity showed that two populations differed in their response to selection. Esterase activity increased as a correlated response to pyrethroids selection in one population but not in others. No changes in either resistance or esterase activity were detected in control lines suggesting that both resistance and esterase activity had a genetic basis (Shehukin and Wool, 1994).

Singh *et al.* (1998b) conducted electrophoretic studies with tris glycine buffer on *B. tabaci* collected from different locations in Punjab and recorded appreciable variability in populations of whitefly from Ludhiana, Faridkot, Bhatinda and Abohar on the basis of number, pattern, frequency and density of bands. They further observed that high density and frequency of specific esterase bands manifested in different locational populations were perhaps responsible for sequestration of organophosphate insecticides.

2.4.4. Thrips

Analysis of the products from metabolism *in vivo* of the radiolabelled insecticides indicated involvement of p450 monooxygenases in resistance to diazinon and bendiocarb (Zhao *et al.*, 1994; 1995b). Zhao *et al.* (1994) observed altered AChE with reduced sensitivity to diazinon contributed to diazinon resistance in the selected population.

In five organophosphates and four carbamates selected population of *F. occidentalis* AChE was inhibited less by two of the organophosphates and one of carbamates and more by one organophosphate and one carbamate (Liu *et al.*, 1994). The insecticide inhibition profiles indicated the presence of altered AChE in the selected population but sensitivity to inhibition depended on the anticholinesterase insecticide.

A slight increase in the esterase activity to α-napthyl acetate was observed in *F. occidentalis* resistant to methiocarb (Jensen, 1998; 2000). The involvement of glutothione-S-transferase and acetyl choline esterase (AChE) was also observed in conferring resistance to methiocarb.

Table 1. Insecticides found effective against *Aphis gossypii* under field condition

Insecticide	Dose	Reference
Cotton		
Monocrotophos	0.05%	Sundaramurthy and Subbiah (1971); Natarajan *et al.* (1997)
Fenvalerate	0.03%	Mundiwale *et al.* (1983)
Dimethoate, phosphamidon, thiometon, vamidothion, formothion	-	Patel *et al.* (1984)
Monocrotophos, chlorpyriphos, methyl demeton, endosulfan	0.03% & 0.05%	Nagia *et al.* (1989)
Imidacloprid 70WS	10 & 15g/kg seed	Mote *et al.* (1993)
	5 & 10g/kg seed	Dandale *et al.* (2001)
Alpha cypermethrin Deltamethrin Cypermethrin Quinalphos	30g a.i./ha 12.5g a.i./ha 50g a.i./ha 500g a.i./ha	Dhawan and Simwat (1997)
Triazophos 40 EC Cypermethrin	400-600g a.i./ha 60g a.i./ha	Sharma *et al.* (1999)
Acetamiprid	10g a.i./ha	Kumar *et al.* (1999)

Monocrotophos Deltamethrin	400g a.i./ha 12.5g a.i./ha	Lingappa *et al.* (2001)
Methyl demeton	300g a.i./ha	Dandale *et al.* (2001)
Thiamethoxam 70 WS Imidacloprid 600 FS Imidacloprid 70 WS	2.8 & 4.3 g/kg seed 9 & 12ml/kg seed 7.5g/kg seed	Vadodaria *et al.* (2001)
Okra		
Imidacloprid 70 WS	10 & 15g/kg seed	Mote *et al.* (1994)
Imidacloprid 600 FS Imidacloprid 70 WS	12ml/kg seed 10g/kg seed	Siva Veerapandian (2000)

Table 2. Insecticides found effective against *Amrasca devastans* under field condition

Insecticide	Dose	Reference
Cotton		
Dicrotophos, monocrotophos	0.02 %	Singh *et al.* (1973)
Methyl demeton Dimethoate	0.1% 0.03%	Ramesh Gera and Chopra (1975)
Methyl demeton, monocrotophos	0.05%	Viswanathan and Abdul Kareem (1983)
Methidathion, methyl demeton	0.01%	Vidhyasekhar *et al.* (1989)

Imidacloprid 70WS	10g & 15g/kg seed	Mote *et al.* (1993)
	5 & 10g/kg seed	Dandale *et al.* (2001)
Dimethoate Dichlorvos, monocrotophos, phosphamidon	220 g.a.i./ha 50g a.i./ha	Bhalla *et al.* (1994)
Cypermethrin + chlopyriphos	0.09%	Srinivasan *et al.* (1995); Pawar *et al.* (1997); Dhawan and Simwat (1997)
Alpha cypermethrin Deltamethrin Cypermethrin Quinalphos	30g a.i./ha 12.5g a.i./ha 50g a.i./ha 500g a.i./ha	Dhawan and Simwat (1997)
Methyl demeton	0.05%	Santhini and Uthamasamy (1997)
Imidacloprid 70 WS Imidacloprid 200SL	3g/kg 0.005%	Gupta *et al.* (1998)
Imidacloprid 70 WS	5 g/kg	Regupathy *et al.* (1999a)
Acetamiprid	10g a.i./ha	Kumar *et al.* (1999)
Triazophos 40 EC Cypermethrin	400-600g a.i./ha 60g a.i./ha	Sharma *et al.* (1999)
Imidacloprid 70 WS	10g/kg seed	Patil *et al.* (1999, 2001)
Acetamiprid 20 SP	26.25g/kg seed	Patil *et al.* (2001)

Insecticide	Dose	Reference
Methyl demeton	300g a.i./ha	Dandale *et al.* (2001)
Thiamethoxam 70 WS Imidacloprid 600 FS Imidacloprid 70 WS	2.8 & 4.3 g/kg seed 9 & 12ml/kg seed 7.5g/kg seed	Vadodaria *et al.* (2001)
Thiamethoxam 25 WG Imidacloprid 200 SL	25g a.i./ha 20g a.i./ha	Dhawan and Simwat (2002)
Okra		
Methyl demeton Dimethoate	0.03% 0.025%	Regupathy and Jayaraj (1973)
Monocrotophos	0.04 %	Patel *et al.* (1980)
Dimethoate, monocrotophos	0.04 %	Singh and Mishra (1988)
Cypermethrin, fenvalerate Deltamethrin	0.006% 0.002%	Dahiya *et al.* (1990)
Dimethoate	600 g a.i./ha	Nagia *et al.* (1992)
Imidacloprid 70 WS	10 & 15g/kg seed	Mote *et al.* (1994)
Fenvalerate	0.005%	Mishra and Singh (1996)
Monocrotophos	500 g a.i./ha	Rai and Satpathy (1999)
Endosulfan Monocrotophos	700 g a.i./ha, 500 g a.i./ha	Satpathy and Rai (1999)
Imidacloprid 600 FS Imidacloprid 70 WS	12ml/kg seed 10g/kg seed	Siva Veerapandian (2000)

Brinjal		
Quinalphos	0.1 & 0.05%	Subbaratnam and Butani (1982)
	0.05%	Kumar *et al*. (1988) Thanki and Patel (1999)
Monocrotophos Phosphamidon	0.04% 0.03%	Mall *et al*. (1996)
Deltamethrin, quinalphos Quinalphos+cypermethrin Cypermethrin+chlorpyriphos	0.05% 0.01% 0.09%	Anil Kumar (2001a)

Table 3. Insecticides found effective against *Bemisia tabaci* under field condition

Insecticide	Dose	Reference
Cotton		
Triazophos	0.01%	Melamed Majdar *et al*. (1984)
Chlorpyriphos	450g a.i./ha	Renou and Chenet (1989)
	0.75 & 1 kg a.i./ha	Narasimha Rao *et al*. (1996)
	5 & 10g/kg seed	Dandale *et al*. (2001)
Triazophos Profenofos	0.1% 1.5l/ha	Venugopal Rao *et al*. (1990); Vadodaria *et al*. (1998)
Brinjal		

Quinalphos	0.05%	Subbaratnam and Butani (1982); Sushil Kumar and Padam (1992)
Cypermethrin	0.01%	Clement Peter and Govindarajulu (1994)
Triazophos, chlorpyriphos, quinalphos	0.05%	Anil Kumar *et al.* (2001b)
Tomato		
Imidacloprid	10g/kg seed treatment + 0.04% root dip	Walunj and Mote (1995)

Table 4. Insecticides found effective against *Thrips tabaci* under field condition

Insecticide	Dose	Reference
Cotton		
Fenvalerate	0.03%	Mundiwale *et al.* (1983)
Methyl demeton	0.1%	Murugan *et al.* (1975)
Imidacloprid 70WS	10 & 15g/kg seed	Mote *et al.* (1993)
Alpha cypermethrin Deltamethrin Cypermethrin Quinalphos	30g a.i./ha 12.5g a.i./ha 50g a.i./ha 500g a.i./ha	Dhawan and Simwat (1997)
Triazophos 40 EC Cypermethrin	400-600g a.i./ha 60g a.i./ha	Sharma *et al.* (1999)
Methyl demeton	300g a.i./ha	Dandale *et al.* (2001)
Thiamethoxam 70 WS Imidacloprid 600 FS Imidacloprid 70 WS	2.8 & 4.3 g/kg seed 9 & 12ml/kg seed 7.5g/kg seed	Vadodaria *et al.* (2001)

CHAPER III
MATERIALS AND METHODS

The research work on insecticide resistance in sucking pests of cotton *viz.*, *A. gossypii*, *A. devastans*, *B. tabaci* and *T. tabaci* was carried out as per the objectives at Department of Agricultural Entomology, Agricultural College and Research Institute, TNAU, Coimbatore during 2001-2003. The materials used and methods employed in the study are presented hereunder.

3.1 Collection of test insects

The test insects *viz.*, *A. gossypii*, *A. devastans*, *B. tabaci* and *T. tabaci* were collected from different regions of Tamil Nadu (Fig .1) for two phases of study.

During the first phase, the test insects were collected from the TNAU farm, Coimbatore, Tamil Nadu. The population of *A. gossypii* was maintained continuously for seven generations and that of *A. devastans* for four generations without exposure to pesticides to calibrate discriminating doses.

During the second phase, the test insects were collected from different locations of Tamil Nadu (Table 5) for making a survey on the level of resistance by applying discriminating dose. The LC_{50} and LC_{95} values were computed for different populations of Tamil Nadu for making comparison among the populations.

3.2. Culturing of test insects

The test insects *viz.*, *A. gossypii* and *A. devastans* required for the studies were reared on potted plants of MCU-5 cotton. Test insects were reared without exposure to insecticides under insectary conditions at 36 ± 1^{o} C. The cotton seeds were sown in the pots (25 x 25 cm) in a staggered manner at weekly intervals. As the germination progresses, the seedlings were covered with the mylar film cages in order to prevent the egg laying by insects other than the test insects and to prevent from natural enemies without exposure to insecticides. Cylindrical mylar film cages of size 30 cm diameter and 70 cm height were used for the studies (Plate 1). All the cages were provided with proper ventilation by covering the top of cages with muslin cloth.

3.2.1. Aphid, *A. gossypii*

Wingless adult aphids of uniform size were released on cotton plants with the help of a fine camel hair brush for larviposition. The insects were cultured for seven continuous generations.

3.2.2. Leafhopper, *A. devastans*

Batches of cotton plants were inoculated with adult leafhoppers with the help of aspirators and test tubes and confined for 24h for oviposition. The plants with freshly laid eggs were placed in the culture cages for further rearing of the required stage. The leafhoppers were cultured continuously for four generations.

3.3. Insecticide dilutions

The required dilutions were prepared from the formulated products of the insecticides using distilled water. The test doses were arrived after preliminary range finding tests for constructing log-concentration-probit-mortality (lcpm) lines. The details of the insecticide formulations used are furnished in Table 6.

3.4. Bioassay

3.4.1. Aphid, *A. gossypii*

The apterous adult aphids of ca 1.45mm size and weighing ca 0.19mg (Plate 2) were taken from the culture. Each replication consisted of ten aphids and there were three replications. Bioassays were conducted following the procedure based on the standard *B. tabaci* susceptibility test, IRAC method No.8 developed and recommended by Insecticide Resistance Action Committee with slight modification.

The experimental setup consisted of two disposable cups, one as inner test chamber and the other as outer water reservoir (Plate 4). The cup which served as the inner test chamber was taken and a hole was pierced in the centre on the bottom side of the cup.

The young green uncontaminated cotton leaves were selected and the petiole was cut to a length of approximately four centimeter. The leaves were dipped in the concentrations for five seconds holding the petiole with fine forceps. Care was taken to avoid the damage to the petiole. Then the leaves were left for drying in the open air by placing the leaves on the filter paper for 20 minutes. The petiole of the leaf was passed through the inner cup and the wingless adult aphids were released at the rate of ten aphids using fine camel hair brush on the leaf (Plate 5) per cup and the cup was covered with muslin cloth tightened with rubber band. A small amount of water was placed in a second cup and the test cup was placed inside that, so that it was supported by the protruding petiole. Observations on mortality of aphids were recorded after 48 h. The results were expressed as percentage mortality.

This test was conducted on wingless adult aphids cultured in glasshouse from first to seventh generation. First generation of field collected aphid populations was used. Median lethal concentration (LC_{50}) and LC_{95} were estimated for all the generations tested and for the population collected from each location. The tentative discriminating doses were fixed based on the LC_{95} of susceptible population of Coimbatore and Kumbakonam and the discriminating doses are as follows.

Insecticide	Discriminating dose (ppm)	Population
Thiamethoxam	10	Coimbatore (F7)
Imidacloprid	10	Kumbakonam
Monocrotophos	20	Coimbatore (F7)
Dimethoate	50	Coimbatore (F7)
Methyl demeton	220	Kumbakonam
Acephate	40	Coimbatore (F7)

3.4.2. Leafhopper, *A. devastans*

The third instar nymphs of ca 1.35 mm size and weighing ca. 0.13mg (Plate 3) from the culture maintained were used for the bioassay conducted as detailed under the section 3.4.1 for aphid.

This test was conducted for first to fourth generation of Coimbatore population and for first generation of field collected populations of leafhoppers.

The tentative discriminating doses were fixed based on the LC_{95} of susceptible population of Coimbatore for thiamethoxam and monocrotophos and discriminating doses for imidacloprid, dimethoate, methyl demeton and acephate proposed by Jeyapradeepa and Regupathy (2002) were used and the doses are as follows.

Insecticide	Discriminating dose (ppm)
Thiamethoxam	0.008
Imidacloprid	0.005
Monocrotophos	0.55
Dimethoate	400
Methyl demeton	800
Acephate	850

3.4.3. Whitefly, *B. tabaci*

Adult leaf dip bioassay followed by Elbert and Nauen (1996) was used. Leaf discs (45mm dia) were cut from medium sized cotton leaves (MCU-5) using a cork borer (Plate 6) and dipped in discriminating doses for five seconds, then dried on a filter paper in open air for 20 min. The bases of small, ventilated polythene petridishes (50 mm dia) were filled with agar gel (12 g/lit, 5 ml). The leaf discs were placed on the agar with their adaxial surface downwards. Adult whiteflies (Plate 7) collected from the field using aspirator were anesthetized using carbon dioxide. A flow rate meter was attached to the outlet of carbon dioxide cylinder which shows the pressure of the escaping gas with an adjustment knob and the gas flow from carbon dioxide cylinder was regulated at the rate of 2.5 ml/sec. The mouth of the tube was closed with the thumb for 20 seconds. The anesthetized insects were placed on a black cloth. Using a fine camel hair brush, 20 adults (mixed sex) were then transferred on to the treated leaf discs and the system was covered with a ventilated lid (Plate 8). Directly after they had recovered from narcosis, the petridishes were placed upside down to stimulate the normal feeding orientation of the whiteflies. The adults not recovered were assessed. Leaf discs immersed in water alone served as control. The test was replicated thrice. Whitefly mortality was scored after 48h exposure to the insecticides.

Discriminating doses followed by PAU, Ludhiana (Regupathy *et al.,* 1998) were used for monitoring.

Insecticide	Discriminating dose (ppm)
Thiamethoxam	10
Imidacloprid	10
Acephate	100
Monocrotophos	100
Triazophos	10
Cypermethrin	50
Endosulfan	5

3.4.4. Thrips, *T. tabaci*

Leaf dip bioassay method used by Elbert and Nauen (1996) was followed. Leaf discs (45mm dia) were cut from medium sized cotton leaves (MCU-5) using a cork borer and dipped in different insecticide dilutions for five seconds, then dried on filter paper in open air for 20 min. The bases of small, ventilated polythene petridishes (50 mm dia) were filled with agar gel (12 g/lit, 5 ml). The leaf discs were placed on the agar with their adaxial surface downwards. Second instar thrips (Plate 9) were collected from the field using aspirator and placed on a black cloth. Using a fine camel hair brush, twenty thrips were then transferred on to the treated leaf disc and the system was covered with a lid (Plate 10). Leaf discs immersed in water alone were served as controls. The test was replicated thrice. Mortality was recorded 48h after exposure to the insecticides.

3.5. Monitoring insecticide resistance

To study the level of insecticide resistance in different cotton growing areas of Tamil Nadu, IRAC method No.8 for aphid and leafhopper and the method of Elbert and Nauen (1996) for whiteflies and thrips were followed for bioassay. The test insects *viz., A. gossypii, A. devastans, B. tabaci* and *T. tabaci* collected from the fields in Coimbatore, Bhavanisagar, Dharapuram, Vaigaidam, Annamalai Nagar, Trichy, Aduthurai, Kumbakonam, Srivilliputtur and Vellore were used for bioassay. In the distant places monitoring was done once in a season where as in Coimbatore it was done at fortnightly intervals.

3.6. Statistical analysis

Log-concentration-probit mortality lines were computed by Finney's probit analysis (Regupathy and Dhamu, 2001).

The corrected percentage of mortality was worked out using the formula (Abbott, 1925).

$$\text{Percentage corrected mortality} = \frac{\text{Percentage test mortality} - \text{Percentage control mortality}}{100 - \text{Percentage control mortality}}$$

3.6.1. Susceptibility index and rate of resistance decline

Susceptibility indices were calculated based on LC_{50} and LC_{95} obtained for the final generation of Coimbatore population, maintained without insecticide exposure in the glass house (Regupathy and Dhamu, 2001).

$$\text{Susceptibility index} = \frac{LC_{50} \text{ of } F_1}{LC_{50} \text{ of } F_n} \quad \text{or} \quad \frac{LC_{95} \text{ of } F_1}{LC_{95} \text{ of } F_n}$$

The rate resistance decline (R) used to quantify the rate of changing LC_{50} when the selection pressure is stopped was estimated by the formula;

$$R = \frac{\text{Log (final } LC_{50}) - \text{log (initial } LC_{50})}{n}$$

Where n is the number of generations not exposed to insecticide,

final LC_{50} is the LC_{50} after n generations without selection and

initial LC_{50} is the LC_{50} of the parental generation before n generations of selection.

The number of generations (G) required for ten fold decrease in the LC_{50} value was calculated using the formula;

$$G = R^{-1}$$

3.6.2. Resistance Ratio or Resistance Factor

The intensity of resistance of a population or a strain of insects to a particular insecticide is frequently quoted as the Resistance Factor (RF) or Resistance Ratio (RR). RF/RR was calculated by the formula;

$$\text{RF or RR at } LC_{50} = \frac{LC_{50} \text{ of Resistant Strain (RS)}}{LC_{50} \text{ of Susceptibility Strain (SS)}}$$

For each discriminating dose screen, the total number of insect's dosed and total mortality was computed. The percentage survival was calculated

Percentage survival = [1-(Number dead /number tested)] x 100

Also, pooled binomial standard error was calculated:

$$= \sqrt{\frac{p(100-p)}{n-1}}$$

Where,

p = Percentage of insects surviving discriminating dose

n = Total number of insects tested that week (Regupathy and Dhamu, 2001).

Table 5. Sampling locations for monitoring insecticide resistance in sucking pests of cotton in Tamil Nadu (Fig. 1)

S. No.	Location	Crop on which collected	Insecticide use pattern
1.	Tamil Nadu Agricultural University farm, Coimbatore	Cotton, brinjal, bhendi	dimethoate, methyl demeton, dimethoate
2.	Bhavanisagar, Erode Dt.	Cotton	dimethoate, methyl demeton
3.	Dharapuram, Erode Dt.	Cotton	methyl demeton, acephate, dimethoate, monocrotophos
4.	Vaigaidam, Theni Dt.	Cotton	methyl demeton, dimethoate, acephate, cypermethrin
5.	Annamalai Nagar, Cuddalore Dt.	Brinjal and bhendi	dimethoate, methyl demeton, acephate, monocrotophos
6.	Trichy	Brinjal	methyl demeton, dimethoate, cypermethrin
6.	Aduthurai, Thanjavur Dt.	Cotton	dimethoate, methyl demeton, acephate, monocrotophos
7.	Kumbakonam, Thanjavur Dt.	Cotton	neem
8.	Srivilliputtur, Virudhunagar Dt.	Cotton	dimethoate, methyl demeton
9.	Vellore	Cotton, brinjal	dimethoate, methyl demeton, monocrotophos

Table 6. Insecticides used for bioassay

Insecticide	IUPAC Name		*Source*
Neonicotinoids			
Thiamethoxam (Actara 25 WG)	N – (2 – chloro – thiazol – 5 yl – methyl) – N’’ – nitro - quanidine	25 per cent WG	*Syngenta India Ltd., Mumbai*
Imidacloprid (Confidor 17.8 SL)	1(6 – chloronicotinyl) 2 nitro iminoimidaz – obidine	17.8 per cent SL	Bayer India Ltd., Mumbai
Organophosphates			
Monocrotophos (Nuvacron 36 WSC)	Dimethyl phosphate of 3 hydroxy-N-methyl-cis-crotonamide	36 per cent WSC	Syngenta India Ltd, Mumbai.
Dimethoate (Rogor 30 EC)	O, O – dimethyl – S – (N – methyl carbamoyl methyl) phosphoro thiolothionate	30 per cent EC	Rallis India Ltd., Bangalore
Methyl demeton (Metasystox 25 EC)	O, O – dimethyl – S – (2 – ethyl sulfinyl) ethyl thiophosphate	25 per cent EC	Bayer India Ltd., Mumbai
Acephate (Acetaf 75 SP)	O, S – dimethyl acetyl phosphoramido thioate	75 per cent SP	Rallis India Ltd., Bangalore
Triazophos (Hostathion 40 EC)	O, O-diethyl O-1-phenyl-1 H-1,2,4-triazol-3-yl phosphorothioate	40 per cent EC	Hoechst India Ltd., Mumbai
Pyrethroids			
Cypermethrin (Cymbush 25E C)	2 cyano – 3 phenoxy benzyl – cis, trans – 3 – (2 – 2 – dichlorovinyl) 2 – 2 dimethyl cyclopropane carboxylate	35 per cent EC	Rallis India Limited, Bangalore
Cyclodienes			
Endosulfan (Thiodan 35 EC)	6,7,8,9,10,10 – hexa chloro - 1,5,5a, 6,9,9a , hexa hydro – 6,9 – methano – 2,4,3 – benzodioxathiepine 3 –oxide (I)	35 per cent EC	Hoechst India Ltd., Mumbai

CHAPTER IV
RESULTS

4.1. Acute toxicity

The acute toxicity of six different insecticides *viz.*, thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate was assessed to the major early season sucking pests *viz., A. gossypii, A. devastans* and *T. tabaci* in terms of LC_{50} and LC_{95}. There was no heterogeneity observed in all the experiments at P = 0.05. The results are presented here under.

4.1.1. *Aphis gossypii*

4.1.1.1. Log Concentration – Probit Mortality (LCPM) of TNAU population

The LC_{50} and LC_{95} values for seven generations of *A. gossypii* collected from, TNAU, Coimbatore are presented in Tables 7-12; Figs 2-7.

The median lethal concentration assessed for F_1 population of Coimbatore was 1.0414, 1.8055, 3.7057, 10.6924, 49.2606 and 5.3284 ppm for thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate respectively (Tables 7-12); the LC_{95} values being 35.2153, 43.4310, 139.4943, 629.6511, 1174.6270 and 130.4890 ppm respectively.

The susceptibility of *A. gossypii* increased after seven generations of insecticide exposure free culturing. The LC_{50} values of *A. gossypii* at F_7 generation for thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate were 0.3412, 0.4583, 1.1866, 3.0096, 12.5980 and 1.4615 ppm respectively and the respective LC_{95} values were 10.8617, 17.9171, 24.9571, 49.1667, 418.4538 and 36.1800 ppm (Tables 7-12; Figs 2-7).

Among the chemicals tested thiamethoxam and imidacloprid were found to be highly toxic followed by other chemicals and the order of toxicity of different insecticides to Coimbatore population was

Based on LC_{50}

F_1 to F_3, F_5 to F_7	:	thiamethoxam > imidacloprid > monocrotophos > acephate > dimethoate > methyl demeton
F_4	:	thiamethoxam = imidacloprid > monocrotophos > acephate > dimethoate > methyl demeton

Based on LC_{95}

F_1, F_2	:	thiamethoxam > imidacloprid > acephate > monocrotophos > dimethoate > methyl demeton
F_3, F_5 to F_7	:	thiamethoxam > imidacloprid > monocrotophos > acephate > dimethoate > methyl demeton
F_4	:	thiamethoxam = imidacloprid > monocrotophos > acephate > dimethoate > methyl demeton

The susceptibility index to different insecticides varied from 3.05 to 3.94 based on LC_{50}. The variation in index was high at LC_{95}; it varied from 2.42 to 12.81 (Table 13).

The rate of resistance decline was negative for all the chemistries tested indicating the susceptibility increased with the succeeding generation. The values varied from -0.0692 to -0.0851 (Table 13). With regard to the number of generations required for 10 fold decrease at LC_{50}, the variation among chemistries was small and varied between 11.75 and 12.72. The minimum observed in imidacloprid and the maximum observed in dimethoate (Table 13).

4.1.1.2. Log Concentration – Probit Mortality (LCPM) of field population from different locations

The LC_{50} and LC_{95} values of the field collected population of *A. gossypii* from various locations of Tamil Nadu are presented in Tables 14-19.

A. gossypii population showed variation in their response to different chemicals. The susceptibility of *A. gossypii* varied with the locations; the variation at LC_{50} was from 0.3412 to 1.3075 for thiamethoxam (Table 14); 0.4028 to 2.3014 for imidacloprid (Table 15); 1.4890 to 5.7260 for monocrotophos (Table 16); 3.5761 to 16.4426 for dimethoate (Table 17); 14.5422 to 69.7572 for methyl demeton (Table 18) and from 1.7222 to 6.6925 ppm for acephate (Table 19). Greater variation was seen at LC_{95}. It varied from 7.8824 to 40.5397 for thiamethoxam (Table 14); 9.5245 to 49.4703 for imidacloprid (Table 15); 37.4237 to 188.2971 for monocrotophos (Table 16); 57.4144 to 776.6293 for dimethoate (Table 17); 222.3473 to 3062.874 for methyl demeton (Table 18) and from 36.0650 to 176.2598 ppm for acephate (Table 19).

Kumbakonam population was highly susceptible irrespective of the chemicals tested whereas the populations of Dharapuram and Vellore were less susceptible.

The order of toxicity of different insecticides from sampling location was

Based on LC_{50}

All locations	:	thiamethoxam ≥ imidacloprid > monocrotophos > acephate > dimethoate > methyl demeton

Based on LC_{95}

Bhavanisagar, Aduthurai, Kumbakonam, Srivilliputtur, Vellore	:	thiamethoxam ≥ imidacloprid > acephate ≥ monocrotophos > dimethoate > methyl demeton
Dharapuram, Vaigaidam	:	thiamethoxam ≥ imidacloprid > monocrotophos ≥ acephate > dimethoate > methyl demeton
Annamalai Nagar	:	imidacloprid ≥ thiamethoxam > monocrotophos ≥ acephate > dimethoate > methyl demeton

The resistance ratios calculated are presented in Table 20. The resistance ratios were higher for the population of Dharapuram and Vellore. The resistance ratio of Dharapuram population at LC_{95} varied from 4.68 for monocrotophos to 13.78 for methyl demeton and for Vellore population it varied from 4.11 for thiamethoxam to 13.53 for dimethoate. The resistance ratios were lower for the populations of Annamalai Nagar and Vaigaidam. The resistance ratio of Annamalai Nagar population at LC_{95} varied from 2.20 (monocrotophos) to 4.83 (dimethoate) and for Vaigaidam population it was between 2.35 (monocrotophos) and 8.62 (dimethoate) (Table 20).

4.1.2. *Amrasca devastans*

4.1.2.1. Log Concentration – Probit Mortality (LCPM) of TNAU population

The LC_{50} and LC_{95} values for four generations of *A. devastans* from Coimbatore are presented in Tables 21-23.; Figs 8-10.

The LC_{50} and LC_{95} values declined with the succeeding generations. The LC_{50} values declined from 0.00087 to 0.00045 for thiamethoxam (Table 21; Fig. 8); 0.00101 to 0.00052 for imidacloprid (Table 22; Fig. 9) and from 0.08013 to 0.05818 ppm for monocrotophos (Table 23; Fig. 10); the respective LC_{95} values declined from 0.06721 to 0.00825; 0.08861 to 0.00833 and from 0.62984 to 0.54695 ppm.

Thiamethoxam was found to be highly toxic to *A. devastans* followed by imidacloprid and monocrotophos. The order of toxicity of different insecticides to Coimbatore population irrespective of generations was

At LC_{50} and LC_{95} : thiamethoxam ≥ imidacloprid > monocrotophos

The susceptibility index at LC_{50} was low; it varied from 1.38 for monocrotophos to 1.94 for imidacloprid. At LC_{95} wide variation was observed; the variation being 1.15 (monocrotophos) and 10.64 (imidacloprid) (Table 24).

For all the chemicals tested the rate of resistance decline was negative; the R value being -0.0347 – -0.0721 (Table 24). The number of generations required for 10 fold decrease at LC_{50} was 13.97, 13.87 and 28.82 for thiamethoxam, imidacloprid and monocrotophos respectively (Table 24).

4.1.2.2. Log Concentration – Probit Mortality (LCPM) of field population from different locations

The median lethal concentration and LC_{95} values for *A. devastans* collected from various locations of Tamil Nadu are presented in Tables 25-30.

The variation was observed in both LC_{50} and LC_{95} values among the populations from different locations for different insecticides tested. The susceptibility was maximum for thiamethoxam. The LC_{50} value varied from 0.0005 to 0.0010 for thiamethoxam (Table 25); 0.00056 to 0.00109 for imidacloprid (Table 26); 0.0538 to 0.0955 (Table 27) for monocrotophos; 38.5430 to 163.4182 for dimethoate (Table 28); 40.9672 to 169.2637 for methyl demeton (Table 29) and from 35.0521 to 87.9657 ppm for acephate (Table 30).

The trend was similar at LC_{95} as well. The LC_{95} values ranged between 0.01850 and 0.08824 for thiamethoxam (Table 25); 0.02995 and 0.11855 for imidacloprid (Table 26); 0.47005 and 0.95130 for monocrotophos (Table 27); 1172.49900 and 4971.63800 for dimethoate (Table 28); 537.25250 and 6553.71000 for methyl demeton (Table 29) and between 1293.66000 and 5368.78900 ppm for acephate (Table 30).

The population from Kumbakonam was highly susceptible for all the chemistries. The low susceptibility was recorded for Dharapuram population followed by Vellore population.

The order of susceptibility of different populations based on LC_{95} was:

Bhavanisagar, Dharapuram	:	thiamethoxam ≥ imidacloprid > monocrotophos > dimethoate > acephate > methyl demeton
Vaigaidam, Aduthurai, Srivilliputtur, Vellore	:	thiamethoxam ≥ imidacloprid > monocrotophos > acephate > dimethoate > methyl demeton
Kumbakonam	:	imidacloprid ≥ thiamethoxam > monocrotophos > methyl demeton > dimethoate > acephate
Coimbatore	:	acephate > dimethoate > methyl demeton

In general the resistance ratios were lower for monocrotophos and higher for methyl demeton. The resistance ratios calculated at LC_{50} and LC_{95} for different populations of *A. devastans* are presented in Table 31. Very high resistance ratio was observed for Dharapuram and Vellore populations whereas it was low for Aduthurai and Vaigaidam populations. The resistance ratio for Dharapuram population at LC_{95} ranged from 1.63 for monocrotophos to 12.20 for methyl demeton and for Aduthurai population it was from 1.37 (monocrotophos) to 7.18 (methyl demeton).

4.1.3. Log Concentration – Probit Mortality (LCPM) of *Thrips tabaci* field population from different locations

The acute toxicity of three insecticides was tested for *T. tabaci* collected from eight locations of Tamil Nadu. The results are presented in Tables 32-34.

The variation in LC_{50} and LC_{95} values was observed among the populations of different locations. The Kumbakonam population was highly susceptible as indicated from the lowest LC_{50} and LC_{95} values for all the insecticides tested; the LC_{50} and LC_{95} values being 0.0571 and 1.1446 for thiamethoxam (Table 32); 0.0390 and 0.6914 for imidacloprid (Table 33) and 94.1882 and 999.0683 ppm for dimethoate (Table 34) respectively.

Dharapuram population was less susceptible for all the chemistries tested compared to other population; the LC_{50} and LC_{95} values being 0.0971 and 2.6076 for thiamethoxam; 0.0713 and 1.9650 for imidacloprid and 171.5809 and 4818.1210 ppm for dimethoate respectively.

Among the insecticides imidacloprid was highly toxic followed by thiamethoxam and dimethoate. The order of toxicity to different insecticides from sampling locations was based on LC_{50} and LC_{95}.

All locations : imidacloprid ≥ thiamethoxam > dimethoate

The resistance ratio was low for imidacloprid and thiamethoxam and high for dimethoate. The resistance ratio at LC_{95} was higher when compared to that at LC_{50}. The resistance ratios at LC_{50} ranged between 1.11 and 1.83 and between 1.21 and 4.82 at LC_{95} (Table 35). Among the populations the higher resistance ratios were registered for the Dharapuram population and lower value for Aduthurai and Bhavanisagar populations.

4.2. Monitoring of Insecticide resistance

4.2.1. *A. gossypii*

The resistance in *A. gossypii* population to different insecticides was monitored using discriminating dose (DD) screens following IRAC method No. 8. The DD (ppm) were arrived at considering F_7 of Coimbatore population and F_1 of Kumbakonam population for six different insecticides *viz.*, 10 for thiamethoxam and imidacloprid, 20 for monocrotophos, 50 for dimethoate, 220 for methyl demeton and 40 for acephate. The monitoring was done during October 2002 to April 2003 continuously at fortnightly intervals in Coimbatore and one time survey in other locations.

4.2.1.1. Coimbatore population (Table 36; Fig. 11)

a. **Thiamethoxam:** The per cent survival varied from 10.4 to 19.0; the maximum survival was observed during second fortnight of October and the resistance frequency was low during first fortnight of March.

b. **Imidacloprid:** The resistance frequency varied between 10.4 and 17.0 per cent. Maximum level was observed during second fortnight of March and the minimum level during first fortnight of December.

c. **Monocrotophos:** The survival to monocrotophos varied from 11.4 to 22.5 per cent. The low level was observed during second fortnight of April and the higher level during first fortnight of February.

d. **Dimethoate:** The resistance frequency ranged from 15.6 to 25.3 per cent. The high level of resistance was during first fortnight of February and the low level of resistance was noticed during first fortnight of January.

e. **Methyl demeton:** The resistance frequency to methyl demeton ranged between 13.5 and 20.0 per cent. During the second fortnight of April the low level survival and the high level during second fortnight of March was observed.

f. **Acephate:** The resistance frequency of Coimbatore population to acephate varied from 13.0 to 21.4 per cent. The highest level of per cent survival was noticed during first fortnight of February and the lowest level during first fortnight of December.

4.2.1.2. Survey on insecticide resistance in *A. gossypii* populations from different locations of Tamil Nadu (Table 37; Fig 12)

F_1 of *A. gossypii* populations collected from nine locations were assessed one time for resistance by applying DD of various insecticides.

a. **Thiamethoxam:** The resistance frequency was high in Trichy population (20.4%) followed by Bhavanisagar and Srivilliputtur (18.4%) population. The lowest resistance frequency was observed in the population of Kumbakonam (9.0%).

b. **Imidacloprid:** The resistance frequency to imidacloprid was high (20.0%) in Srivilliputtur and it was less in Kumbakonam population (11.0%).

c. **Monocrotophos:** The resistance to monocrotophos varied from 12.1 to 30.6 per cent. Dharapuram population recorded maximum level followed by Vellore (29.0%) and Annamalai Nagar (24.5%) populations and Kumbakonam population recorded the lowest.

d. **Dimethoate:** Maximum resistance frequency (31.0%) was observed in Vellore population and the minimum level (11.2%) was recorded in Kumbakonam population.

e. **Methyl demeton:** The per cent survival of *A. gossypii* to methyl demeton varied between 12.2 and 29.0. The per cent survival was high in Dharapuram population followed by populations of Annamalai Nagar (27.3%) and Vellore (26.3%). The lower level of per cent survival was recorded in Kumbakonam population.

f. **Acephate:** The population of Dharapuram registered maximum per cent survival of 25.3 per cent followed by Vellore population (19.0%). The lowest resistance frequency was observed in Kumbakonam population. Resistance level was high than 15 per cent in almost all the locations tested.

The populations of *A. gossypii* from Dharapuram and Vellore recorded higher per cent survival to almost all the chemicals tested whereas the Kumbakonam population was found to be highly susceptible to all the chemistries tested.

The order of resistance in different *A. gossypii* populations to various insecticides was:

Thiamethoxam	:	Trichy > Srivilliputtur = Bhavanisagar ≥ Annamalai Nagar ≥ Dharapuram > Aduthurai ≥ Vellore ≥ Vaigaidam > Kumbakonam
Imidacloprid	:	Srivilliputtur ≥ Dharapuram ≥ Annamalai Nagar ≥ Trichy ≥ Aduthurai ≥ Bhavanisagar ≥ Vellore ≥ Vaigaidam > Kumbakonam
Monocrotophos	:	Dharapuram > Vellore > Annamalai Nagar > Bhavanisagar ≥ Aduthurai ≥ Vaigaidam > Trichy > Srivilliputtur > Kumbakonam
Dimethoate	:	Vellore > Dharapuram > Trichy ≥ Annamalai Nagar > Bhavanisagar ≥ Srivilliputtur ≥ Aduthurai = Vaigaidam > Kumbakonam
Methyl demeton	:	Dharapuram > Annamalai Nagar ≥ Vellore > Bhavanisagar > Aduthurai > Vaigaidam ≥ Srivilliputtur ≥ Trichy > Kumbakonam
Acephate	:	Dharapuram > Vellore > Aduthurai ≥ Trichy ≥ Annamalai Nagar ≥ Vaigaidam ≥ Bhavanisagar ≥ Srivilliputtur > Kumbakonam

4.2.2. *A. devastans*

The resistance frequency of *A. devastans* population to different insecticides was monitored using DD screens following IRAC method No. 8. The DD arrived at considering F_4 of Coimbatore population for thiamethoxam (0.008) and monocrotophos (0.55) and DD developed by Jeyapradeepa and Regupathy (2002) for imidacloprid (0.005), dimethoate (400), methyl demeton (800) and acephate (850) were used. The monitoring was done during October 2002 to April 2003 continuously at fortnightly intervals for dimethoate, methyl demeton and acephate for Coimbatore population and one time survey for all the insecticides in other locations.

4.2.2.1. Monitoring insecticide resistance in Coimbatore population (Table 38; Fig 13)

a. **Dimethoate:** The resistance frequency varied between 14.3 and 21.9 per cent. Maximum level was observed during second fortnight of October and the minimum level was observed during second fortnight of March.

b. **Methyl demeton:** The per cent survival varied from 13.5 to 20.4 per cent; the maximum survival was observed during second fortnight of October and the low level was noticed during first fortnight of December.

c. **Acephate:** The per cent survival to acephate varied from 12.9 to 18.8 per cent. The high level was observed during second fortnight of October and the lower level during first fortnight of December.

4.2.2.2. Survey on insecticide resistance in *A. devastans* population from different locations of Tamil Nadu (Table 39; Fig. 14)

A. devastans populations collected from different locations were tested for resistance by applying DD of various insecticides.

a. **Thiamethoxam:** The resistance frequency was maximum in Vellore population (19.0%) followed by Trichy and Annamalai Nagar (18.0%) populations and it was lowest in the population of Kumbakonam (6.0%).

b. **Imidacloprid:** The resistance frequency to imidacloprid was high (20.0%) in Trichy and Vellore populations and it was less in Kumbakonam population (7.0%).

c. **Monocrotophos:** The resistance to monocrotophos varied from 13.0 to 26.0 per cent. Dharapuram population recorded maximum per cent survival followed by Vellore and Trichy (24.0%) populations whereas the Kumbakonam population recorded the lowest per cent survival.

d. **Dimethoate:** The resistance frequency was high in the population of Vellore (28.3%) followed by Dharapuram (25.0%) and Srivilliputtur (21.4%). The lowest resistance frequency was observed in the Kumbakonam population (11.0%).

e. **Methyl demeton:** The resistance frequency to methyl demeton was high (26.0%) in Vellore and it was less in Kumbakonam (7.1%) and Bhavanisagar (12.0%) populations. Populations from all other locations registered more than 15.00 per cent resistance.

f. **Acephate:** The resistance frequency to acephate varied from 7.2 to 21.2 per cent. Vellore population recorded high resistance frequency followed by Bhavanisagar (19.0%) and Srivilliputtur (18.2%) populations. Kumbakonam population recorded the lowest per cent survival.

Populations from Vellore and Srivilliputtur recorded higher per cent survival to almost all the chemicals tested and the Kumbakonam population recorded the lowest per cent survival to all the insecticides tested.

The order of resistance in *A. devastans* population from various locations to various insecticides was:

Thiamethoxam	:	Vellore ≥ Annamalai Nagar = Trichy ≥ Aduthurai ≥ Dharapuram > Srivilliputtur > Vaigaidam ≥ Coimbatore ≥ Bhavanisagar > Kumbakonam
Imidacloprid	:	Vellore = Trichy > Annamalai Nagar = Aduthurai > Dharapuram > Bhavanisagar ≥ Vaigaidam = Coimbatore ≥ Srivilliputtur > Kumbakonam
Monocrotophos	:	Dharapuram > Vellore = Trichy > Annamalai Nagar ≥ Aduthurai ≥ Coimbatore = Vaigaidam > Bhavanisagar ≥ Srivilliputtur > Kumbakonam
Dimethoate	:	Vellore > Dharapuram > Srivilliputtur ≥ Aduthurai ≥ Annamalai Nagar > Trichy > Vaigaidam ≥ Bhavanisagar > Kumbakonam

Methyl demeton	:	Vellore > Srivilliputtur ≥ Annamalai Nagar ≥ Vaigaidam ≥ Dharapuram ≥ Aduthurai ≥ Trichy > Bhavanisagar > Kumbakonam
Acephate	:	Vellore > Bhavanisagar ≥ Srivilliputtur ≥ Aduthurai ≥ Vaigaidam ≥ Annamalai Nagar ≥ Dharapuram > Trichy > Kumbakonam

4.2.3. *B. tabaci*

The resistance frequency of *B. tabaci* population to various insecticides was monitored using DD screens following the method suggested by Elbert and Nauen (1996). The DD screen followed by PAU, Ludhiana (Regupathy *et al.*, 1998) for seven different insecticides *viz.*, thiamethoxam (10), imidacloprid (10), monocrotophos (100), acephate (100), triazophos (10), cypermethrin (50) and endosulfan (5) was used. The monitoring was done during February to May 2003.

4.2.3.1. Coimbatore population (Table 40; Fig 15)

a. **Thiamethoxam:** The survival of *B. tabaci* to thiamethoxam varied from 14.0 to 18.7 per cent; the maximum survival was observed during second fortnight of March and the minimum survival was noticed during second fortnight of February and first fortnight of May.

b. **Imidacloprid:** The resistance frequency varied between 13.0 and 20.0 per cent. Maximum level was observed during second fortnight of March and the minimum level was observed during second fortnight of February.

c. **Monocrotophos:** The per cent survival to monocrotophos varied from 18.7 to 28.0. The low level was observed during first fortnight of March and the higher level during first fortnight of May.

d. **Acephate:** The resistance frequency ranged from 18.7 to 26.0 per cent. The high level was observed during second fortnight of April and the low level was noticed during second fortnight of March.

e. **Triazophos:** The resistance frequency to triazophos ranged between 26.0 and 34.0 per cent. During the second fortnight of May the low level of per cent survival was observed and the high level was noticed during first fortnight of May.

f. **Cypermethrin:** The resistance frequency of Coimbatore population to cypermethrin varied from 28.0 to 35.0 per cent. The highest level of per cent survival was noticed during second fortnight of February and the lowest level during second fortnight of March.

g. **Endosulfan:** The resistance frequency of *B. tabaci* to endosulfan ranged from 20.0 to 28.0 per cent. The high level was observed during second fortnight of May and the low level was noticed during first fortnight of May.

4.2.3.2. Survey on insecticide resistance in *B. tabaci* populations from different locations of Tamil Nadu (Table 41; Fig 16)

B. tabaci population collected from different locations and F_1 generations were tested for resistance by applying DD of various insecticides.

a. **Thiamethoxam:** The resistance frequency was high (22.0%) in the populations of Dharapuram, Trichy and Srivilliputtur and the lowest was observed in Kumbakonam population (10.0%).

b. **Imidacloprid:** The resistance frequency to imidacloprid was high (24.0%) in Dharapuram and Trichy followed by Aduthurai, Vaigaidam and Srivilliputtur (20.0%), Annamalai Nagar (18.0%), Bhavanisagar and Vellore (16.0%) and Kumbakonam (8.0%) populations.

c. **Monocrotophos:** The resistance frequency to monocrotophos varied from 14.0 to 30.0 per cent. Vellore population recorded the highest per cent survival followed by Dharapuram (28.0%) and Annamalai Nagar and Bhavanisagar (24.0%) populations. Kumbakonam population recorded the lowest per cent survival.

d. **Acephate:** Maximum resistance frequency (26.0%) was observed in Dharapuram and Annamalai Nagar populations and the minimum (12.0%) was recorded in Kumbakonam population.

e. **Triazophos:** The survival of *B. tabaci* to triazophos varied between 12.0 to 26.0 per cent. The per cent survival was the highest in Dharapuram population followed by Vaigaidam (24.0%) population. The lower level of per cent survival was recorded in Kumbakonam population.

f. **Cypermethrin:** The population of Dharapuram registered the highest survival rate (30.0%) followed by Vellore population (28.0%). The lowest level of survival rate was observed in Kumbakonam population (14.0%). Resistance level exceeded 20 per cent in all other locations tested.

g. **Endosulfan:** The resistance frequency was the highest in Vellore population (24.0%) followed by that of Dharapuram and Annamalai Nagar (22.0%) populations. The lowest resistance frequency was observed in Kumbakonam (10.0%) population.

The populations from Vellore, Dharapuram and Trichy locations recorded higher rate of survival to almost all the chemicals tested. The Kumbakonam population was found to be highly susceptible to all the chemistries tested recording less than 15 per cent survival.

The order of insecticide resistance in *B. tabaci* in various locations being

Thiamethoxam	:	Dharapuram = Srivilliputtur = Trichy > Vellore = Annamalai Nagar = Aduthurai > Vaigaidam > Bhavanisagar > Kumbakonam
Imidacloprid	:	Dharapuram = Trichy > Aduthurai > Srivilliputtur > Vaigaidam > Annamalai Nagar > Vellore = Bhavanisagar > Kumbakonam
Monocrotophos	:	Vellore > Dharapuram > Annamalai Nagar = Bhavanisagar > Srivilliputtur = Vaigaidam > Aduthurai = Trichy > Kumbakonam
Acephate		Annamalai Nagar = Dharapuram > Vaigaidam = Vellore > Aduthurai = Bhavanisagar > Srivilliputtur = Trichy > Kumbakonam
Triazophos		Dharapuram > Vaigaidam > Trichy = Vellore > Annamalai Nagar = Srivilliputtur > Aduthurai = Bhavanisagar > Kumbakonam
Cypermethrin		Dharapuram > Vellore > Annamalai Nagar > Aduthurai = Srivilliputtur = Trichy > Bhavanisagar > Vaigaidam > Kumbakonam
Endosulfan		Vellore > Annamalai Nagar = Dharapuram > Aduthurai = Bhavanisagar > Srivilliputtur = Trichy = Vaigaidam > Kumbakonam

CHAPTER V
DISCUSSION

The results obtained from the investigations carried out on acute toxicity of insecticides and monitoring of insecticide resistance in early season sucking pests of cotton are discussed below:

5.1. Acute toxicity

5.1.1. *A. gossypii*

One of the most important factors governing the management of insecticide use is the availability of sound baseline data on the susceptibility of the target pest to the toxicant.

The acute toxicity of neonicotinoids and organophosphate compounds to *A. gossypii* populations from different locations *viz*., Coimbatore, Bhavanisagar, Dharapuram, Vaigaidam, Annamalai Nagar, Aduthurai, Kumbakonam, Srivilliputtur, Vellore was assessed using IRAC method No. 8.

The susceptibility of *A. gossypii* varied with location; the variation at LC_{50} was from 0.3412 to 1.3075 for thiamethoxam (Table 14); 0.4028 to 2.3014 for imidacloprid (Table 15); 1.4890 to 5.7260 for monocrotophos (Table 16); 3.5761 to 16.4426 for dimethoate (Table 17); 14.5422 to 69.7572 for methyl demeton (Table 18) and 1.7222 to 6.6925 ppm for acephate (Table 19). Greater variation was seen at LC_{95}. It varied from 7.8824 to 40.5397 ppm for thiamethoxam (Table 14); 9.5245 to 49.4703 ppm for imidacloprid (Table 15); 37.4237 to 188.2971 ppm for monocrotophos (Table 16); 57.4144 to 776.6293 ppm for dimethoate (Table 17); 222.3473 to 3062.874 ppm for methyl demeton (Table 18) and from 36.0650 to 176.2598 ppm for acephate (Table 19).

Such type of variation in the susceptibility (LD_{50} in μg/ml) of *A. gossypii* populations was reported to imidacloprid (0.05642 – 0.07793) at the time of introduction in Tamil Nadu (Kumar, 1998), and monocrotophos (0.2425 – 3.5158) in China (Cheng Guilin *et al.*, 1997) and to oxy demeton methyl (LC_{50} in ppm) (1.8 – 3745.0) in Hawai

(Hollingsworth *et al.*, 1994) and for *L. erysimi* to dimethoate (1.4-2.5) in China from Beijing suburbs (Zheng Bingzong *et al.*, 1997).

Among the populations, the Kumbakonam population was highly susceptible irrespective of the chemicals tested. The major crop in this particular location is rice and it is cultivated in about 75-100ha during June-January (Fig. 17a). During the summer season, when water availability is not sufficient to take up second crop of rice, the farmers are taking up cotton crop in limited area 40-50ha during February – June in this location. The pesticide survey in this location revealed that the farmers are not using pesticides due to the success of IPM programmes on rice and cotton promoted by the State Department of Agriculture (SDA) through Farmers Field School (FFS). Non-use of insecticides on cotton might be the possible reason for high susceptibility of the Kumbakonam population.

The less susceptibility of Dharapuram and Vellore populations might be due to frequent sprayings and high selection pressure. The resistance ratio of Dharapuram population at LC_{95} varied from 4.68 for monocrotophos to 13.78 for methyl demeton and for Vellore population it varied from 4.11 for thiamethoxam to 13.53 for dimethoate (Table 20).

The major commercial crop in Dharapuram is cotton on which sucking pests are the predominant (Fig. 17b). The farmers are using nearly 10-15 rounds of insecticides to control the pests of cotton in the surveyed area which ultimately resulted in less susceptibility to insecticides. In Vellore the summer season cotton crop is alternated with brinjal, bhendi and tomato during the availability of water (August-January) (Fig. 17c). For the present studies the test insects were collected not only from cotton crop but also from bhendi and brinjal. Since these two are the major alternative hosts for cotton pests, this lead to exposure to wide spectrum of insecticides. The selection pressure depending on the use pattern might be one of the possible reasons for the resistance development.

The susceptibility of Coimbatore population was tested with relaxation of selection pressure to pesticides by rearing the population in glasshouse for seven continuous generations. The results indicated that the susceptibility gradually increased with the succeeding generation, as evident from the decline in LC_{50} and LC_{95} values.

The LC_{50} and LC_{95} values at F_7 generation declined to 0.3412 and 10.8617 ppm for thiamethoxam and to 0.4583 and 17.9171 ppm for imidacloprid respectively. The values for F_7 generation of Coimbatore population without selection pressure and that of Kumbakonam population were comparable with the data obtained by Mathirajan and Regupathy (2002) (LD_{50} - 0.3488 ppm) for thiamethoxam and by Kumar (1998), (LC_{50} - 0.309 ppm) for imidacloprid at the time of introduction of these chemicals in Tamil Nadu. Further the LC_{50} value obtained by Elbert *et al.* (1991) (LC_{50} - 0.30ppm) also indicated that the values obtained in the present investigations could be used as baseline data for fixing discriminating dose for thiamethoxam and imidacloprid.

The LC_{95} values of *A. gossypii* of monocrotophos, dimethoate, methyl demeton and acephate declined to 24.9571, 49.1667, 418.4538 and 36.18 ppm respectively through F_7 without exposure to selection pressure (Tables 9-12; Figs 4-7). The LC_{95} of monocrotophos, dimethoate and acephate of highly susceptible population of Kumbakonam, where pesticide were not applied was comparable. However, for methyl demeton LC_{95} value (222.3473 ppm) was less than that observed for F_7 of Coimbatore population.

Such reduction during relaxation of selection pressure had been demonstrated not only in sucking pests but also in lepidopterans. Cheng Guilin *et al.* (1997) obtained the baseline value (LD_{50}) of 0.0017 μg/head for China population against monocrotophos, Hollingsworth *et al.* (1994) (LC_{50}) 1.8 ppm against dimethoate for *A. gossypii* and 0.0092μg/head against dimethoate for *L. erysimi* by Zheng Bingzong *et al.* (1997). In Tamil Nadu, it has been demonstrated in *C. medinalis* (Anandan and Regupathy, 2001), *P. xylostella* (Chandrasekaran, 1994) and *S. litura* (Niranjan Kumar and Regupathy, 2000).

The extent of increase in susceptibility was more in imidacloprid and methyl demeton which required 11.75 and 11.82 generations respectively for 10 fold decrease at LC_{50} whereas it was low in thiamethoxam and monocrotophos for which 14.45 and 14.16 generations were required respectively (Table 13). The susceptibility index of Coimbatore population to different insecticides varied from 3.05 to 3.94 based on LC_{50}. The variation in index was high at LC_{95}; the variation being from 2.42 to 12.81 (Table 13).

Among the chemicals tested, thiamethoxam and imidacloprid were found to be highly toxic. Highly toxic nature of thiamethoxam was reported by Mathirajan and Regupathy (2001) to *A. gossypii*. It was proved to be very toxic and the effectiveness of thiamethoxam and imidacloprid was comparable under field conditions. Imidacloprid was found to be more toxic to *A. gossypii* (Kumar, 1998) and *Aphis craccivora* Koach than methyl demeton (Ramesh Babu and Santharam, 2000) and to apple aphids *Nasonovia ribisnigri* and *M. persicae* than lambdacyhalothrin, deltamethrin, cypermethrin, dimethoate, methyl demeton, primicarb and heptenophos (Barber *et al.*, 1999).

Considering the values obtained for Kumbakonam population and that of F_7 generation of Coimbatore population, the following tentative discriminating doses (ppm) were arrived at based on LC_{95} for six different insecticides *viz.*, 10 for thiamethoxam and imidacloprid, 20 for monocrotophos, 50 for dimethoate, 220 for methyl demeton and 40 for acephate.

5.1.2. *A. devastans*

In the present study, thiamethoxam was found to be highly toxic chemical followed by imidacloprid and monocrotophos. The results are in conformity with the findings of Kalra *et al.* (2001) where they reported thiamethoxam as the most toxic chemical i.e. 2454 times more toxic than malathion and the toxicity order was thiamethoxam > endosulfan = monocrotophos > phosphamidon > oxydemeton methyl > dimethoate > malathion.

Similarly, the toxicity of imidacloprid was reported by Jeyapradeepa and Regupathy (2002); the LC_{50} and LC_{95} values of F_1 population being 0.00056 and 0.00457 respectively.

Chalam and Subbaratnam (1999) observed high toxicity of diafenthiuron to the resistant Guntur population of *A. biguttula biguttula* followed by imidacloprid and thiamethoxam and recommended these chemicals for insecticide resistance management.

The high toxic nature of imidacloprid to cotton leafhopper was also reported by Gupta *et al.* (1998). This was confirmed by the earlier reports of Gul and Gul (1998) (imidacloprid > dimethoate) and Patil *et al.* (1999) (imidacloprid > methyl demeton > dimethoate) under field condition. The toxicity of other chemicals was also reported by Regupathy and Jayaraj (1973) (dimethoate = methyl demeton > disulfoton > phorate), Chinnaiah and Asaf Ali (1999) (acephate > monocrotophos > dimethoate > carbosulfan) and by Manisegaran and Kumaraswami (1994) (methyl demeton > monocrotophos > fenitrothion > dimethoate > phosphamidon) for *A. devastans* under field condition.

The variation was observed in both LC_{50} and LC_{95} values among the population from various locations for different insecticides tested. In general the susceptibility was maximum for thiamethoxam followed by imidacloprid > monocrotophos > methyl demeton > dimethoate > acephate. The toxicity order of methyl demeton, dimethoate and acephate interchanged in the above order in other locations. This might be due to frequent use and subsequent resistance development in different populations of *A. devastans* as a result of selection pressure. The present result is in conformity with the findings of Jeyapradeepa and Regupathy (2002). They observed the LC_{50} values of 153.9, 205.92 and 114.79 ppm to dimethoate, methyl demeton and acephate respectively for F_1 population of Madurai and the respective LC_{95} values being 2722.7, 4466.8 and 3981.1 ppm.

The LC_{50} and LC_{95} values of *A. devastans* declined with the succeeding four generations. The LC_{50} values declined from 0.00087 to 0.00045 ppm for thiamethoxam

(Table 21); from 0.00101 to 0.00052 ppm for imidacloprid (Table 22) and from 0.08013 to 0.05818 ppm for monocrotophos (Table 23); the respective LC_{95} values declined from 0.06721 to 0.00825 ppm; 0.08861 to 0.00833 ppm and from 0.62984 to 0.54695 ppm.

Such reduction during relaxation of selection pressure had been demonstrated in hoppers like *A. devastans* (Jeyapradeepa and Regupathy, 2002) and *N. lugens* (Sujatha, 1994).

The susceptibility index at LC_{50} varied from 1.38 for monocrotophos to 1.94 for imidacloprid. Wide variation was observed in susceptibility index at LC_{95}; it was low for monocrotophos (1.15) and high for imidacloprid (10.64). The number of generations required for 10 fold decrease at LC_{50} was 13.97, 13.87 and 28.82 for thiamethoxam, imidacloprid and monocrotophos respectively (Table 24). With relaxation of selection pressure, the increase in susceptibility was found to be more in the new chemistries, thiamethoxam and imidacloprid indicating the usuage of these chemicals within a shorter period of introduction. Whereas the increase in susceptibility was less in monocrotophos, which was in use since 1970s, may be due to less consumption of this pesticide in this particular location.

Among the populations, Kumbakonam population was more susceptible whereas Dharapuram and Vellore populations were less susceptible. The cropping pattern and insecticide use pattern might be the reason for the susceptibility of Kumbakonam population as discussed earlier.

The LC_{95} value of thiamethoxam for Coimbatore population of F_4 (without selection pressure) was 0.00825 ppm, which is less than that of Kumbakonam population (0.01850 ppm) and that estimated by Mathirajan and Reguapthy (2002) (LD_{50} -0.36). Hence, the value obtained for Coimbatore population is taken for arriving discriminating dose.

The LC_{95} value of imidacloprid for Coimbatore population of F_4 (without selection pressure) was 0.00833 ppm, which is less than that of Kumbakonam population

(0.02995 ppm). Jeyapradeepa and Regupathy (2002) obtained LC_{95} value of 0.00457 ppm earlier. The present value is more than the values obtained earlier, which indicates the usage of the chemical as discussed earlier. Hence, the value of 0.00457 is considered for arriving discriminating dose.

The LC_{95} of insecticides were taken as discriminating dose (ppm) based on the F_4 of Coimbatore population were 0.008 for thiamethoxam and 0.55 for monocrotophos and that developed by Jeyapradeepa and Regupathy (2002), for imidacloprid (0.005) dimethoate (800), methyl demeton (400) and acephate (850) based on the susceptible population (F_6/F_7) of Madurai.

5.1.3. *T. tabaci*

The variation in LC_{50} and LC_{95} values was observed among the populations. The Kumbakonam population was highly susceptible as indicated from the lowest LC_{50} and LC_{95} values for all the insecticides tested; the LC_{50} and LC_{95} values being 0.0571 and 1.1446 ppm for thiamethoxam (Table 32); 0.039 and 0.6914 ppm for imidacloprid (Table 33) and 94.1882 and 999.0683 ppm for dimethoate (Table 34) respectively. Dharapuram population was less susceptible for all the chemistries tested compared to other locations.

Among the insecticides, imidacloprid was highly toxic followed by thiamethoxam and dimethoate. The effectiveness of imidacloprid (Mote *et al.*, 1993; Vadodaria *et al.*, 2001) and thiamethoxam (Vadodaria *et al.*, 2001) as seed treatment was reported under field condition.

The LC_{50} / LC_{95} values obtained for dimethoate in the present studies was in conformity with that reported by Sridhar and Jhansi Rani, (2003). They found the LC_{50}

values of 172.0 and 253.0 ppm in open field and greenhouse populations of *S. dorsalis* respectively.

The variation in susceptibility between the populations had been reported earlier for different chemicals. Morishita (1993) observed differential susceptibility of *Thrips palmi* Karny to fenobcurb, methidathion and cypermethrin between Kishigawa and Inami populations in Japan; the LC_{50} values being 428-821, 137-551 and 16-41 ppm for the Kishigawa population, and 558-1266, 440-911 and 29-76 ppm for the Inami population respectively.

The resistance ratio was low for imidacloprid and thiamethoxam and high for dimethoate. Among the locations, the higher resistance ratios were registered for the population of Dharapuram and lower for Aduthurai and Bhavanisagar populations.

Based on slope function and increased susceptibility, the DD screen was fixed for monitoring the level of insecticide resistance in various locations, for susceptibility of a population can be tested with a single diagnostic concentration for purposes of screening field populations for resistance (WHO, 1976). Use of log-dose and slope estimates earlier for monitoring resistance were pointed out to be sensitive to small changes in resistance frequency, practically when resistance was first appearing in the population. The advantages of using diagnostic concentration rather than a comparison of LD_{50} estimates had been known by Roush and Miller (1986). Diagnostic tests with fixed dose and exposure period were suggested to be more efficient for detecting low frequencies of resistance because all individuals were tested at an appropriate dose and none were wasted on lower dose (ffrench - constant and Roush, 1990).

The concentration - mortality lines are not appropriate for the determination of the preparation of resistant individuals, which can be better accomplished by using a discrimination dose (Roush and Miller, 1986; ffrench-constant and Roush, 1990;

Mink and Boethel, 1992) or diagnostic dose (Halliday and Burnham, 1990). Large fraction of a pest that would otherwise survive field exposure will lower the efficiency of monitoring because some resistant individuals will be killed rather than detected. On the other hand, a diagnostic dose that allows survival of several susceptible individuals will result in identifying false positives. Therefore, under conditions of low resistance intensity, the best monitoring method suggested by ffrench-constant and Roush (1990) was to use discriminating dose for susceptible population.

These type of studies are very limited in sucking pests particularly in *A. gossypii*. In India, DD screen was also successfully used in monitoring insecticide resistance in many insects, *A. devastans* (Jeyapradeepa and Regupathy, 2002), *B. tabaci* (Regupathy *et al.*, 1998), *H. armigera* (Armes *et al*., 1992 a & b; Pasupathy and Regupathy, 1993; Regupathy *et al*., 1999b), *P. xylostella* (Chandrasekaran and Regupathy, 1996; Renuka and Regupathy, 1996) and *S. litura* (Niranjan Kumar and Regupathy, 2000).

5.2. Resistance monitoring

Resistance monitoring techniques play an integral role in resistance management programme and if used before, pesticide treatment can avoid ineffective application (Roush and Miller, 1986 and ffrench–constant and Roush, 1990). The extent of resistance in different populations varied with insecticides. The resistance level in *A. gossypii* and *A. devastans* to different insecticides was monitored using tentative discriminating dose screen during October 2002 to April 2003 and to *B. tabaci* during February to May 2003 continuously at fortnightly intervals in Coimbatore and one time survey in other locations of Tamil Nadu

5.2.1. *A. gossypii*

The mean resistance frequency in Coimbatore population of *A. gossypii* varied from 13.8 for thiamethoxam to 19.3 for dimethoate. The per cent mean survival rate in other locations was higher in Dharapuram and Vellore populations. This might be due to the cropping pattern (Fig. 17) and pesticide use pattern in the surveyed areas as discussed earlier.

The slightly higher level of resistance to dimethoate, monocrotophos, methyl demeton and acephate in the present survey in many areas might be due to the insecticide use pattern. The above organophosphate compounds were used since eighties extensively in Tamil Nadu. Low level of resistance (9.0-20.4%) to thiamethoxam and (11.0-20.00%) imidacloprid in all the areas might be attributed to the low level of consumption in the surveyed areas, as these chemicals were introduced into the market recently.

Variation in the susceptibility among different populations of *A. gossypii* had been observed for various groups of insecticides by Gubran *et al.* (1992) in Sudan Gezira, Hollingsworth *et al.* (1994) in Hawai, Saito *et al.* (1995) in Japan, Cheng Guilin *et al.* (1997) in China and Herron *et al.* (2001) in Australia.

5.2.2. *A. devastans*

The per cent mean survival rate in Coimbatore population of *A. devastans* was 17.8 for dimethoate, 17.7 for methyl demeton and 17.0 for acephate. The maximum mean resistance frequency in other locations was 19.0 (Vellore) for thiamethoxam, 20.0 (Vellore and Trichy) for imidacloprid, 26.0 (Dharapuram) for monocrotophos, 28.3 (Vellore) for dimethoate, 26.0 (Vellore) for methyl demeton and 21.2 (Dharapuram) for acephate.

The slightly higher level of resistance to dimethoate, methyl demeton and monocrotophos seen in the present study in many locations might be due to the pesticide use pattern. The Kumbakonam population was the highly susceptible population, since the farmers are not using pesticides as discussed earlier.

The differential susceptibility among the populations was also observed by Chalam and Subbaratnam (1999) between three different populations of cotton leafhopper in Andhra Pradesh, the Guntur population was relatively more resistant than the populations of Warangal and Kurnool districts to endosulfan, monocrotophos and cypermethrin.

In the earlier studies by Jeyapradeepa and Regupathy (2002) during 1999-2000 in Tamil Nadu, the maximum mean survival rate of 49.0 per cent (Oddanchatram) for dimethoate, 42.7 per cent (Vaigaidam) for methyl demeton and to 43.0 per cent (Oddanchatram) for acephate was observed. The present survey indicated that there is a reduction in the level of resistance to dimethoate, methyl demeton and acephate. This might be due to change in the use pattern of the chemistries.

Earlier, the organophosphates *viz.*, methyl demeton (0.50 lit/ha), monocrotophos (1.25 lit/ha), acephate (1.30 kg/ha) and triazophos (2.0 lit/ha) were recommended for field control by State Department of Agriculture (Anonymous, 1999). Dimethoate, methyl demeton and acephate are anticholineesterases inhibitors whereas the neonicotinoids are ACh receptor agonists (Yamamoto *et al.*, 1995). Hence, the chance for cross resistance between anticholine esterase inhibitors and neonicotinoids and vice versa is less. The newly introduced neonicotinoids thiamethoxam and imidacloprid are mainly used as seed treatment. The commercial seed producers supply only seeds treated with these chemicals. That the selection pressure due to conventional anticholinesterase might have reduced.

5.2.3. *B. tabaci*

The resistance level in *B. tabaci* population to various insecticides was monitored using discriminating dose screens followed at PAU, Ludhiana (Regupathy *et al.*, 1998) following the method suggested by Elbert and Nauen (1996).

The per cent mean survival rate of Coimbatore population was higher for a pyrethroid, cypermethrin (28.0 to 35.0) and OP compound, triazophos (26.0 and 34.0). Resistance studies made during 1997-1998 in Punjab and Andhra Pradesh have shown significant resistance to cypermethrin, acephate and monocrotophos but continued susceptibility to chlorpyriphos, triazophos, endosulfan and imidacloprid (Regupathy *et al.,* 1998). Similar observations were made by Kranthi *et al.* (2001, 2002), wherein *B. tabaci* from different parts of India exhibited moderately high level of resistance to cypermethrin, monocrotophos and methomyl but resistance to endosulfan, chlorpyriphos and triazophos was negligible in the field strains tested.

The slightly higher level of resistance to cypermethrin and monocrotophos was observed in the present survey in different locations of Tamil Nadu. However in other parts of the country the resistance level was very high. In Tamil Nadu whitefly is not a major pest as observed in Punjab. More over in Tamil Nadu the synthetic pyrethroid application was restricted and TNAU has advocated non synthetic pyrethroids due to the problem of resurgence (Anonymous, 1999). When compared to other chemicals cypermethrin recorded higher level of resistance. Though the synthetic pyrethroids are not used, some of the farmers are using to control late season pests. The pest resurgence due to synthetic pyrethroids had been documented (Jayaraj, 1987).

Among the different locations surveyed, Dharapuram (22.0-30.0%) and Vellore (16.0-30.0%) populations recorded slightly higher survival rate, which might be due to the use pattern as discussed earlier.

The differential susceptibility among the populations of *B. tabaci* from different locations was also observed by Prasad *et al.* (1993), Chinnabbai *et al.* (2001) and Balakrishnan *et al.* (2002) in Andra Pradesh, by Sharma and Batra (1995) in Haryana, by

Singh *et al.* (1998a) in Punjab, by Ahmed *et al*. (2002) in Pakistan and by Elbert and Nauen (1996, 2000) in Spain.

There have been no reported cases of control failure in the surveyed regions. Such cases where high LC_{50} and LC_{95} values did not correspond to loss of field efficacy had been reported by Anandan and Regupathy (2003) in *C. medinalis*, Jeyapradeepa and Regupathy (2002) in *A. devastans* in Tamil Nadu and by Denholm *et al.* (1984) in *H. virescens*. However ffrench-constant and Roush (1990) reported that factors such as crop variety, pest population age structure and plant size can introduce variability in results. The high LC_{50} and LC_{95} values of insecticides in some survey locations indicate that failure in field control is possible if present insecticide application trends continue.

CHAPTER VI
SUMMARY

The results of the studies conducted on acute toxicity of six different insecticides *viz.,* thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate to the major early season sucking pests *viz.*, *Aphis gossypii* Glover, *Amrasca devastans* Distant and *Thrips tabaci* Lind. in terms of LC_{50} and LC_{95} and monitoring the resistance level of *A. gossypii*, *A. devastans*, *T. tabaci* and *Bemisia tabaci* Gennadius to different insecticides using discriminating dose screen in Coimbatore population at fortnightly intervals and one time survey in other locations are summarized here.

1. The median lethal concentration to F_1 population of *A. gossypii* from Coimbatore was 1.0414, 1.8055, 3.7057, 10.6924, 49.2606 and 5.3284 ppm for thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate respectively; the LC_{95} values being 35.2153, 43.4310, 139.4943, 629.6511, 1174.627 and 130.489 ppm respectively.
2. The LC_{50} to F_7 generation for thiamethoxam, imidacloprid, monocrotophos, dimethoate, methyl demeton and acephate were 0.3412, 1.4583, 1.1866, 3.0096, 12.598 and 1.4615 ppm respectively and the respective LC_{95} values were 10.8617, 17.9171, 24.9571, 49.1667, 418.4538 and 36.18 ppm.
3. Among the chemicals tested thiamethoxam and imidacloprid were found to be highly toxic followed by monocrotophos = acephate > dimethoate = methyl demeton.
4. The susceptibility index of *A. gossypii* to different insecticides varied between 2.42 and 12.81 at LC_{95}. The number of generations required for 10 fold decrease at LC_{50} varied from 11.75 to 12.72.

5. The susceptibility of *A. gossypii* varied with the locations; the variation at LC_{50} being 0.3412 - 1.3075 for thiamethoxam; 0.4028 - 2.3014 for imidacloprid; 1.489 - 2.726 for monocrotophos; 3.5761 - 16.4426 for dimethoate; 14.5422 - 69.7572 for methyl demeton and 1.7222 - 6.6925 ppm for acephate.

6. At $LC_{95,}$ it varied from 7.8824 to 40.5397 ppm for thiamethoxam; 9.5245 to 49.5397 ppm for imidacloprid; 37.4237 to 188.2971 ppm for monocrotophos; 57.4144 to 776.6293 ppm for dimethoate; 222.3473 to 3062.874 ppm for methyl demeton and 36.065 to 176.2598 ppm for acephate.

7. Among the populations, Kumbakonam population was highly susceptible irrespective of the chemicals tested whereas the population of Dharapuram and Vellore exhibited high resistance. The resistance ratios at LC_{95} were higher for Dharapuram (4.68-13.78) and Vellore (4.11-13.53) populations and lower for the populations of Annamalai Nagar (2.20-4.83) and Vaigaidam (2.35-8.62).

8. The LC_{50} and LC_{95} to Coimbatore *A. devastans* population declined with the succeeding four generations. The LC_{50} values declined from 0.00087 to 0.00045 ppm for thiamethoxam; 0.00101 to 0.00052 ppm for imidacloprid and 0.08013 to 0.05818 ppm for monocrotophos; the respective LC_{95} values declined from 0.06721 to 0.00825 ppm; 0.08861 to 0.00833 ppm and 0.62984 to 0.54695 ppm.

9. Thiamethoxam was found to be highly toxic followed by imidacloprid and monocrotophos.

10. The susceptibility index at LC_{95} was low for monocrotophos (1.15) and high for imidacloprid (10.64). The number of generations required for 10 fold decrease at LC_{50} was 13.97 for thiamethoxam, 13.87 for imidacloprid and 28.82 for monocrotophos.

11. With regard to locations, variation was observed in both LC_{50} and LC_{95} values for different insecticides tested; the LC_{50} value varied from 0.0005 to 0.001 ppm for thiamethoxam; 0.00056 to 0.00109 ppm for imidacloprid; 0.0538 to 0.0955 ppm for monocrotophos; 38.543 to 163.4182 ppm for dimethoate; 40.9672 to 169.2637 ppm for methyl demeton and 35.0521 to 87.9657 ppm for acephate.
12. The LC_{95} values ranged between 0.0185 and 0.08814 ppm for thiamethoxam; 0.02995 and 0.11855 ppm for imidacloprid; 0.4705 and 0.9513 ppm for monocrotophos; 1172.499 and 4971.638 ppm for dimethoate; 537.2525 and 6553.71 ppm for methyl demeton and from 1293.66 and 5368.789 ppm for acephate.
13. Among the populations, Kumbakonam population was highly susceptible for all the chemistries. Dharapuram and Vellore populations were less susceptible.
14. The resistance ratios at LC_{95} were lower for monocrotophos (1.13-2.02) and higher for methyl demeton (7.18-12.20) in all the locations.
15. High resistance ratio was observed for Dharapuram and Vellore populations whereas it was low for Aduthurai and Vaigaidam populations.
16. The acute toxicity of three insecticides to *T. tabaci* showed variation in LC_{50} and LC_{95} values among the populations.
17. The Kumbakonam population was highly susceptible as indicated from the lowest LC_{50} and LC_{95} values; the values being 0.0571 and 1.1446 ppm for thiamethoxam; 0.039 and 0.6914 ppm for imidacloprid and 94.1882 and 999.0683 ppm for dimethoate respectively.
18. Dharapuram population was less susceptible for all the chemistries tested compared to other locations; the LC_{50} and LC_{95} values being 0.0971 and 2.6076 ppm for thiamethoxam; 0.0713 and 1.965 ppm for imidacloprid and 171.5809 and 2986.394 ppm for dimethoate respectively.

19. Among the insecticides imidacloprid was highly toxic followed by thiamethoxam and dimethoate.
20. The tentative discriminating doses (ppm) for monitoring insecticide resistance were fixed for six different insecticides viz., thiamethoxam (10), imidacloprid (10), monocrotophos (20), dimethoate (50), methyl demeton (220) and acephate (40) for *A. gossypii* and thiamethoxam (0.008) and monocrotophos (0.55) for *A. devastans* based on the susceptible populations of Coimbatore and Kumbakonam.
21. Monitoring of insecticide resistance in Coimbatore population of *A. gossypii* from October 2002 to April 2003 revealed that the per cent survival varied from 10.42 to 19.00 for thiamethoxam; 10.42 to 17.00 for imidacloprid; 11.43 to 20.62 for monocrotophos; 5.63 to 25.26 for dimethoate; 13.54 to 20.00 for methyl demeton; 13.04 to 21.43 for acephate.
22. Monitoring of insecticide resistance in *A. devastans* during October 2002 to April 2003 done at fortnightly intervals for Coimbatore population indicated that the resistance frequency varied between 14.29 and 21.98 per cent for dimethoate; 13.48 and 20.41 per cent for methyl demeton; 12.90 and 18.75 per cent for acephate.
23. The resistance frequency of *B. tabaci* for Coimbatore population varied from 14.00 to 18.67 per cent for thiamethoxam; 13.00 to 20.00 per cent for imidacloprid; 18.67 to 28.00 per cent for monocrotophos; 18.67 to 26.00 per cent for acephate; 26.00 and 34.00 per cent for triazophos; 28.00 to 35.00 per cent for cypermethrin; 20.00 to 28.00 per cent for endosulfan.
24. The populations of *A. gossypii* from Dharapuram and Vellore, *A. devastans* from Vellore and Srivilliputtur and *B. tabaci* from

25. Vellore, Dharapuram and Trichy locations recorded higher rate of survival. The Kumbakonam population was found to be highly susceptible to all the test insects and to all the chemistries tested.

Fig 14. Insecticide resistance in *A. devastans* populations to various insecticides

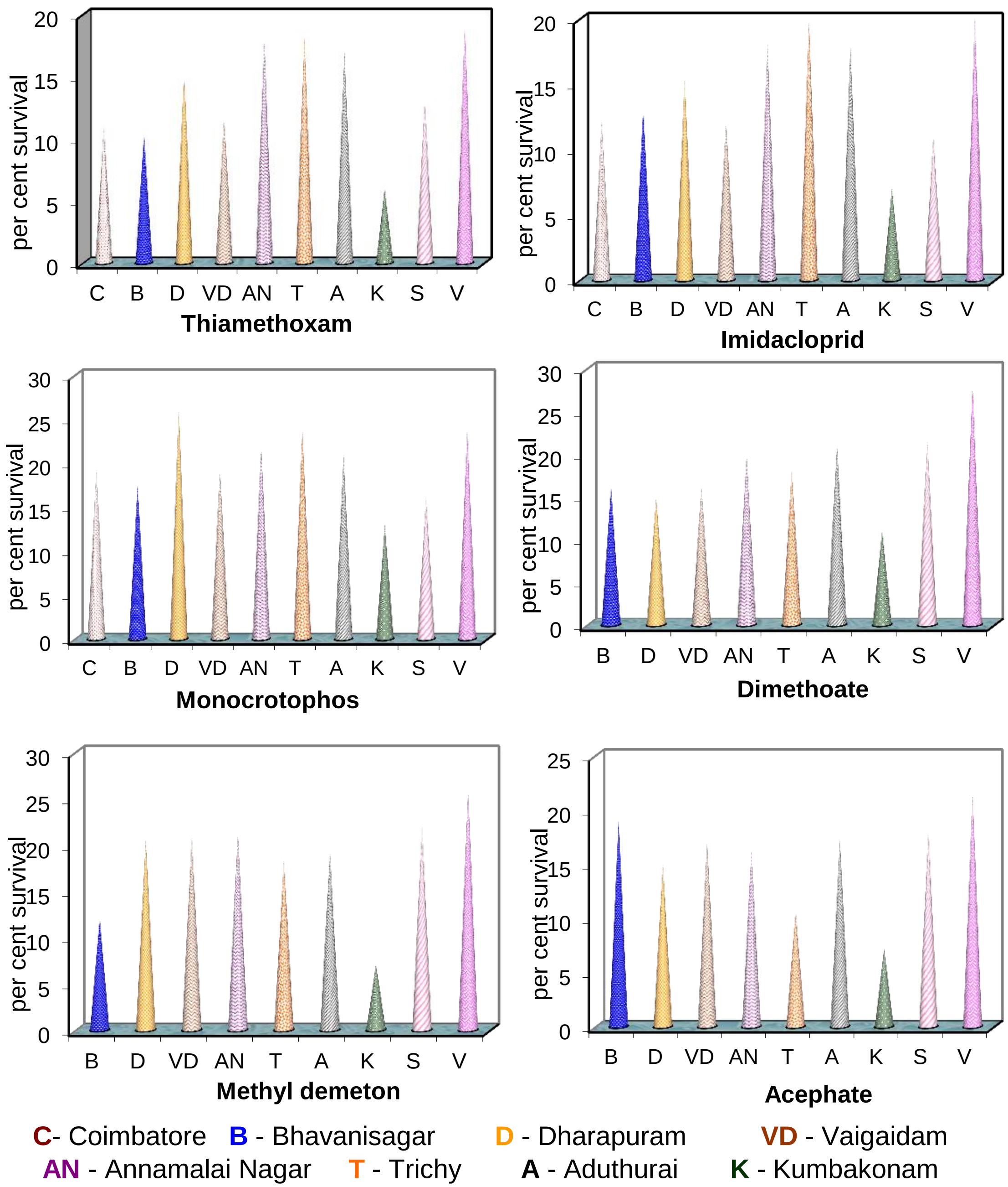
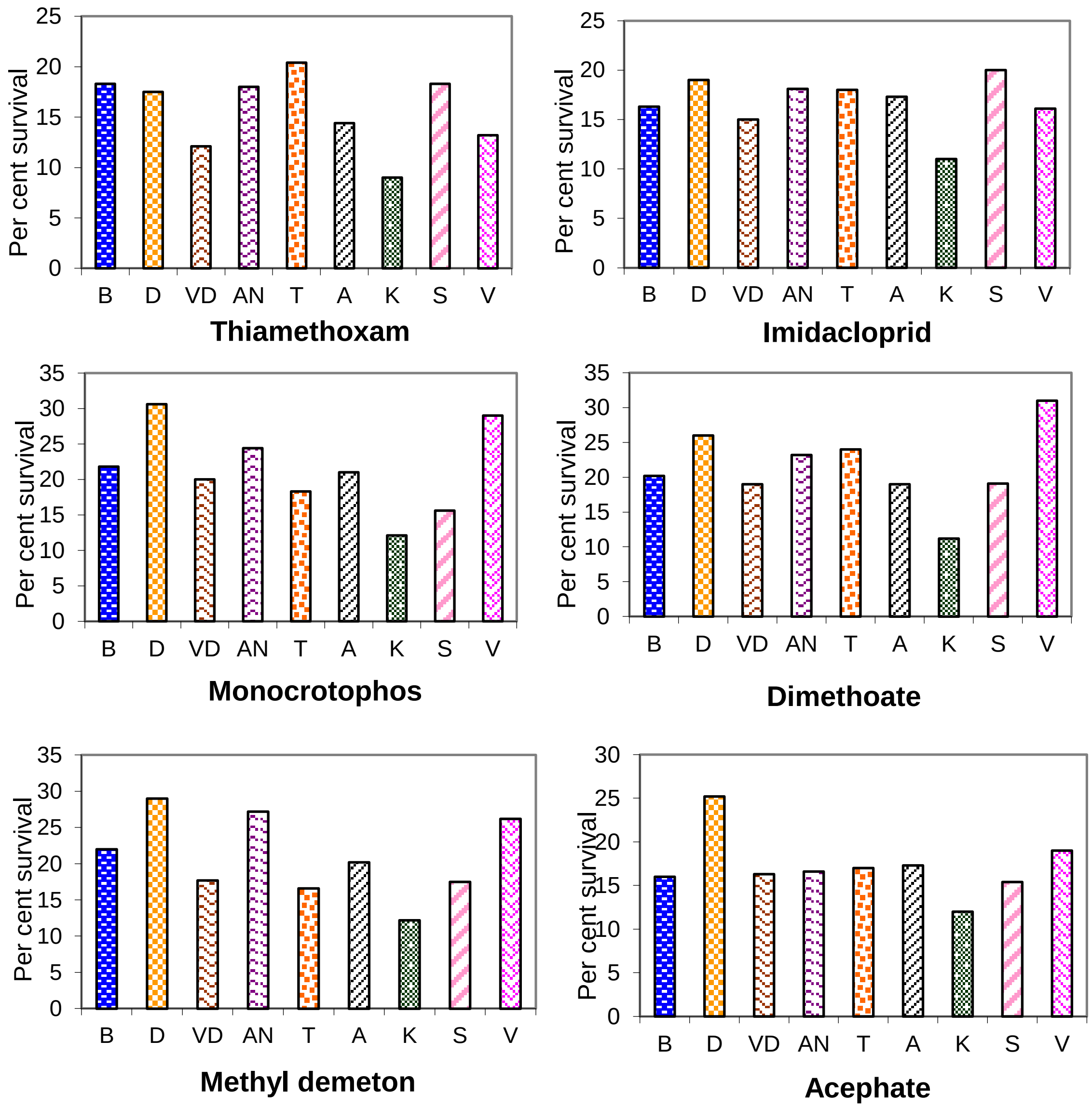


Fig 12. Insecticide resistance in *A. gossypii* populations to various insecticides



B - Bhavanisagar **D** - Dharapuram **VD** - Vaigaidam **AN** - Annamalai Nagar **T** - Trichy **A** - Aduthurai **K** - Kumbakonam **S** -

Fig. 15. Monitoring insecticide resistance in Coimbatore population of *B. tabaci*

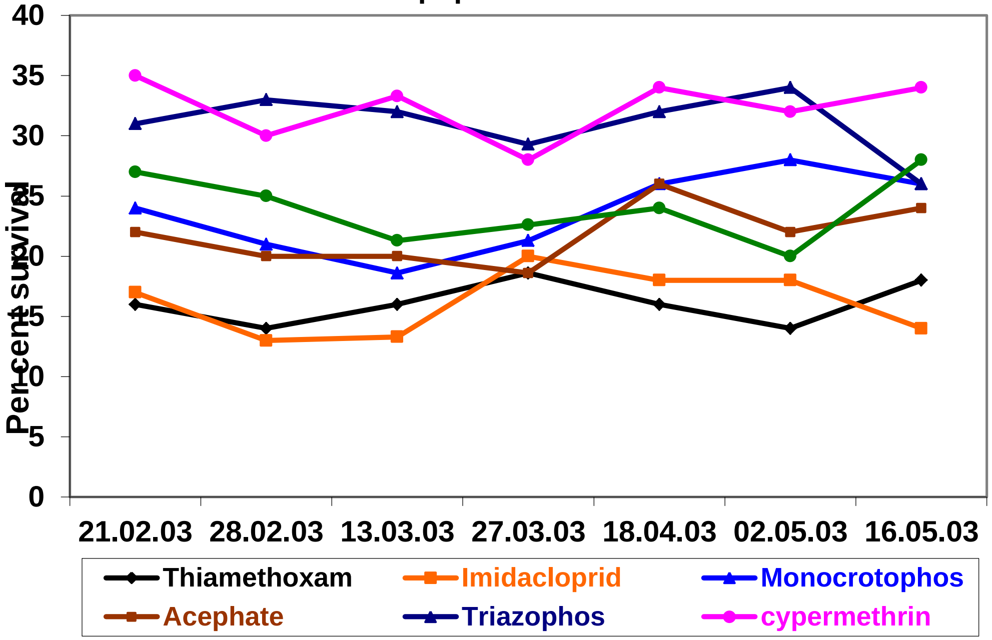


Fig. 13. Monitoring insecticide resistance in Coimbatore population of *A. devastans*

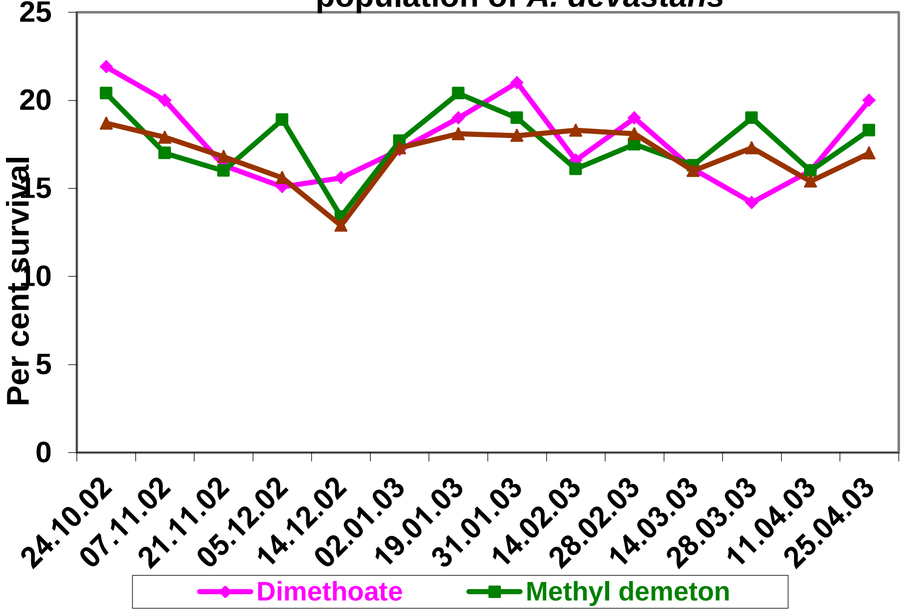


Fig. 11. Monitoring insecticide resistance in Coimbatore population of *A. gossypii*

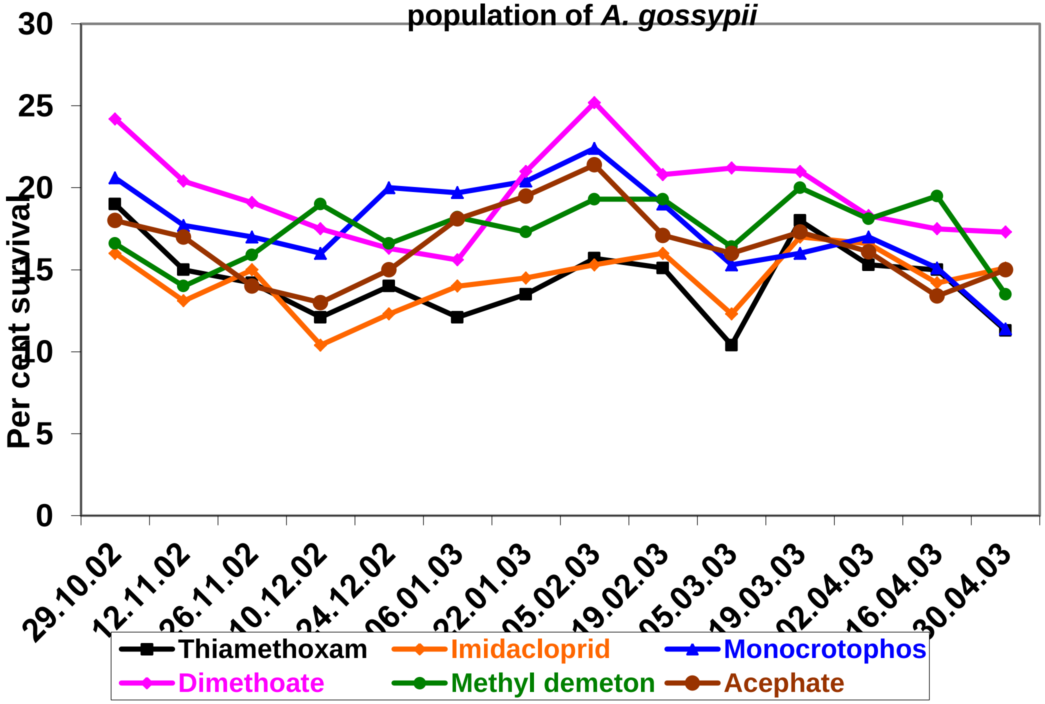


Fig 8. LCPM regression lines for *A. devastans* of Coimbatore population to thiamethoxam

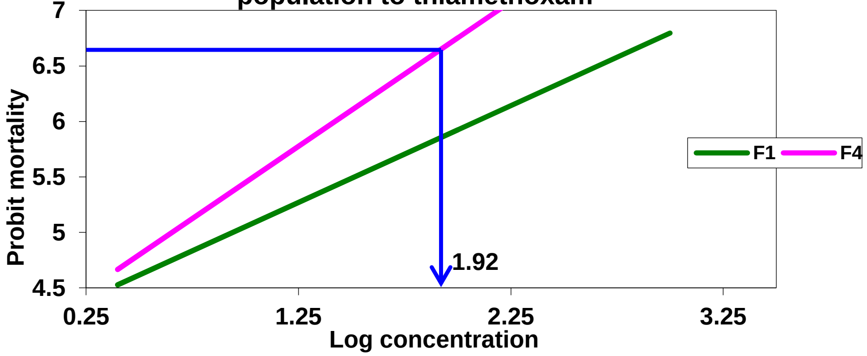


Fig 9. LCPM regression lines for *A. devastans* of Coimbatore population to imidacloprid

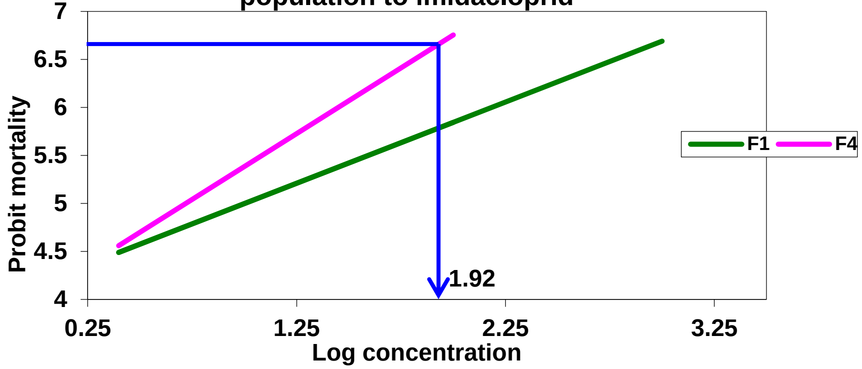


Fig 10. LCPM regression lines for *A. devastans* of Coimbatore population to monocrotophos

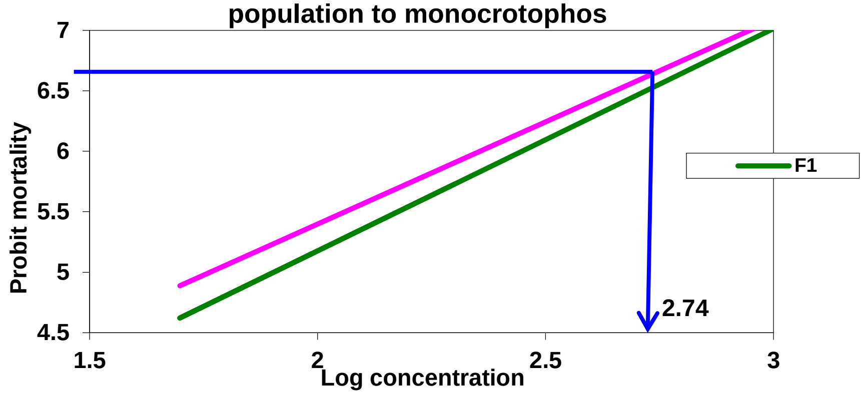


Fig 5. LCPM regression lines for *A. gossypii* of Coimbatore population to dimethoate

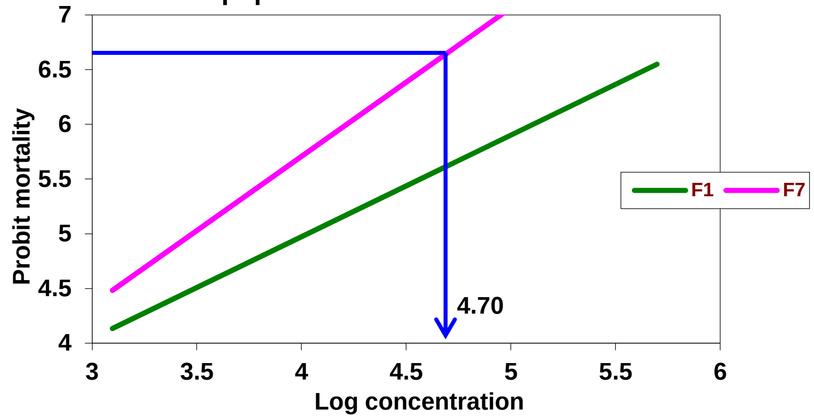


Fig 6. LCPM regression lines for *A. gossypii* of Coimbatore population to methyl demeton

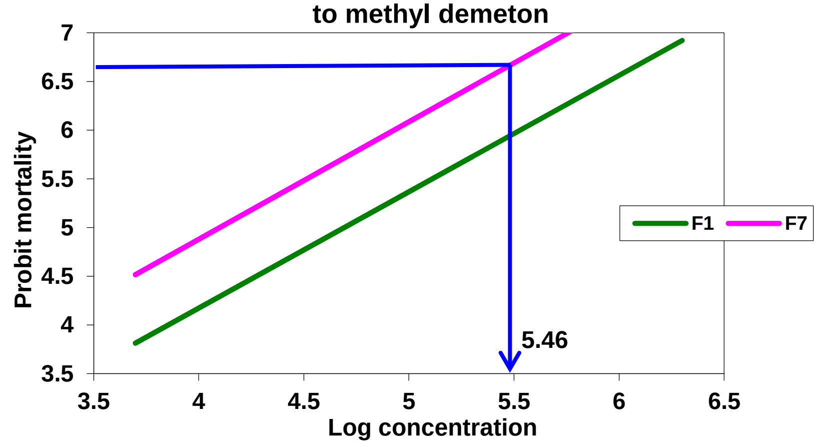


Fig 7. LCPM regression lines for *A. gossypii* of Coimbatore population to acephate

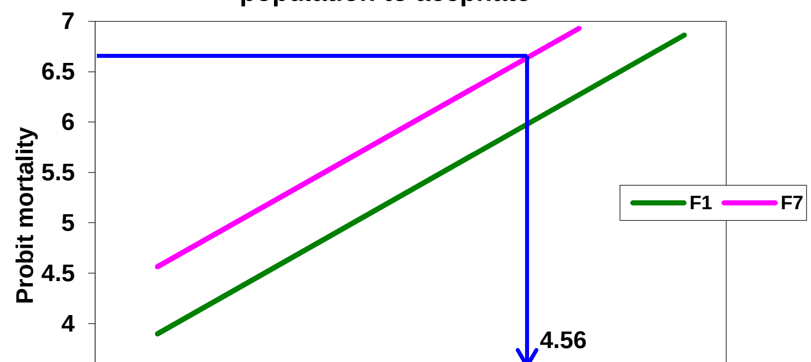


Fig 2. LCPM regression lines for *A. gossypii* of Coimbatore population to thiamethoxam

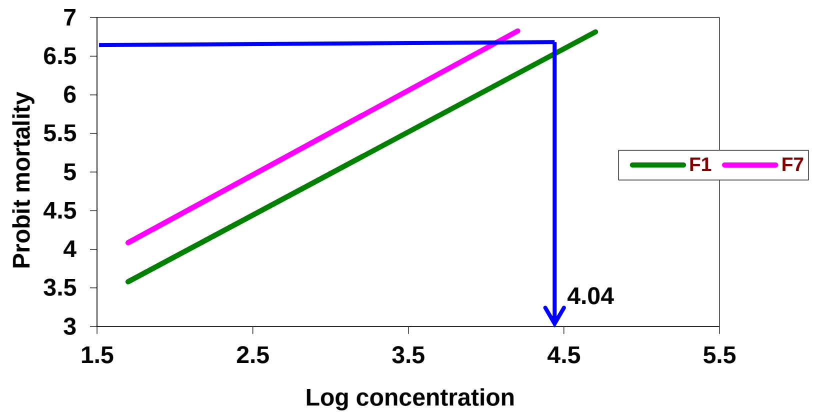


Fig 3. LCPM regression lines for *A. gossypii* of Coimbatore population to imidacloprid

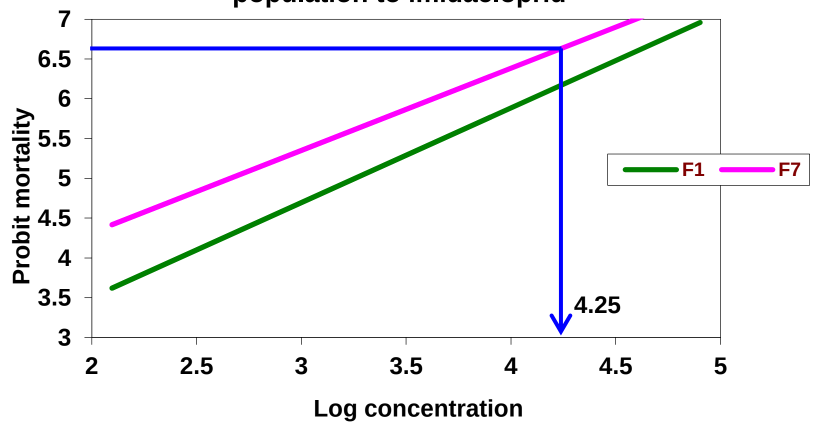
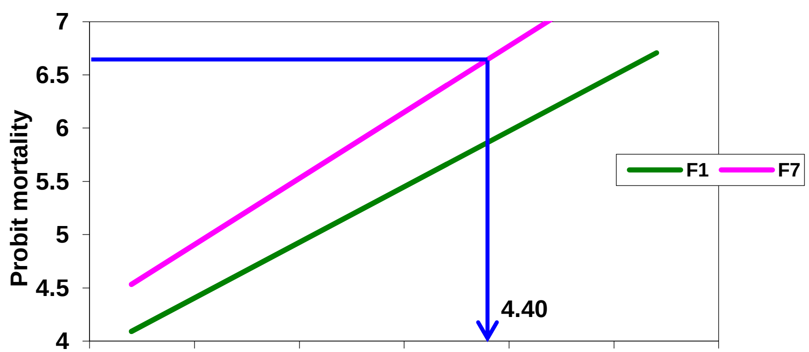


Fig 4. LCPM regression lines for *A. gossypii* of Coimbatore population to monocrotophos



to Coimbatore population of *A. gossypii* by IRAC method No. 8

Generation	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
1	Y = 1.7539 + 1.0757 x	0.4854	1.0414	0.6488	-	1.6715	35.2153	21.9405	-	56.5220
2	Y = 1.7036 + 1.1408 x	0.4056	0.7755	0.5002	-	1.2022	21.4524	13.8375	-	33.2578
3	Y = 1.7309 +1.15628 x	0.2582	0.6719	0.4324	-	1.0441	17.7776	11.4402	-	27.6255
4	Y =1.9143 + 1.0882 x	0.1626	0.6848	0.4233	-	1.1066	22.2382	13.7499	-	35.9666
5	Y =2.0609 + 1.1130 x	0.2180	0.4372	0.2803	-	0.6819	13.1399	8.4241	-	20.4955
6	Y = 1.9437 + 1.1831 x	0.5127	0.3831	0.2513		0.5839	9.4104	6.1736	-	14.3443
7	Y = 2.2275 + 1.0945 x	0.3026	0.3412	0.2159	-	0.5393	10.8617	6.8730	-	17.1653

Table 8. Acute toxicity of imidacloprid to Coimbatore population of *A. gossypii* by IRAC method No. 8

Generation	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
1	Y = 1.1220 + 1.1908 x	0.7636	1.8055	1.1698	-	2.7874	43.4310	28.1449	-	67.0656
2	Y = 1.5813 + 1.0913 x	1.4356	1.3577	0.8143	-	2.2630	43.6616	26.1939	-	72.7780
3	Y = 1.4777 + 1.1916 x	0.1203	0.9028	0.5918	-	1.3788	21.687	14.2102	-	33.1054
4	Y = 1.9143 + 1.0882 x	0.1626	0.6848	0.4233	-	1.1066	22.2382	13.7499	-	35.9666
5	Y= 2.0224 + 1.0943 x	0.6298	0.5261	0.3310	-	0.8364	16.7628	10.5460	-	26.6443
6	Y = 2.2485 + 1.0214 x	0.4690	0.4940	0.3051	-	0.7999	20.1419	12.4383	-	32.6167
7	Y= 2.2506 + 1.0332 x	0.8712	0.4583	0.2847	-	0.7379	17.9171	11.1285	-	28.8470

Table 9. Acute toxicity of monocrotophos to Coimbatore population of *A. gossypii* by IRAC method No. 8

Generation	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
1	Y = 1.2744 + 1.0439 x	0.2594	3.7057	2.3047	-	5.9585	139.4943	86.7551	-	224.2944
2	Y = 1.4011 + 1.0226 x	0.9258	3.3059	2.0267	-	5.3926	134.2147	82.3000	-	218.9273
3	Y = 0.9417 + 1.2306 x	0.2039	1.9852	1.3271	-	2.9696	43.1022	28.8137	-	64.4763
4	Y = 1.0104 + 1.2499 x	0.1994	1.5549	1.0356	-	2.3351	32.1884	21.4338	-	48.3393
5	Y = 1.2076 + 1.2123 x	0.0950	1.3433	0.8601	-	2.0979	30.5483	19.5600	-	47.7096
6	Y = 0.9412 + 1.3150 x	0.2482	1.2206	0.8034	-	1.8544	21.7492	14.3156	-	33.0429
7	Y =1.1774 + 1.2434 x	0.3890	1.1866	0.7530	-	1.8699	24.9571	15.8373	-	39.3285

Table 10. Acute toxicity of dimethoate to Coimbatore population of *A. gossypii* by IRAC method No. 8

Generation	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
1	Y = 1.2557 + 0.9293 x	0.0833	10.6924	6.3045	-	18.1342	629.6511	371.2309	-	1067.8020
2	Y = 1.7500 + 0.8325 x	0.1373	8.0131	4.3984	-	14.6016	758.0537	413.0064	-	1381.0200
3	Y = 1.0816 + 1.0663 x	0.2171	4.7272	2.9723	-	7.5179	164.8542	103.6812	-	262.1803
4	Y = 0.8180 + 1.1839 x	0.1698	3.4064	2.1737	-	5.3383	83.5026	53.2844	-	130.8278
5	Y = 0.4448 + 1.2954 x	0.3764	3.2833	2.1673	-	4.9739	61.1042	40.3346	-	92.5687
6	Y = 0.4464 + 1.2980 x	0.3134	3.2075	2.1238	-	4.8442	59.2525	39.2330	-	89.4874
7	Y = 0.2836 + 1.3559 x	0.2866	3.0096	1.9986	-	4.5320	49.1667	32.6499	-	74.0390

Table 11. Acute toxicity of methyl demeton to Coimbatore population of *A. gossypii* by IRAC method No. 8

Generation	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
1	Y = -0.6041 + 1.1943 x	0.3876	49.2606	32.2107	-	75.3529	1174.627	767.8917	-	1796.8010
2	Y = -0.7179 + 1.2458 x	0.5798	38.8866	25.7454	-	58.7219	813.0667	538.3937	-	1227.7220
3	Y = -0.0883 + 1.1618 x	0.2210	23.9717	15.5310	-	37.0084	624.5971	404.5759	-	964.0510
4	Y = 0.2910 + 1.1028 x	0.2662	18.6122	11.6573	-	29.7235	577.2979	361.4931	-	921.7221
5	Y = 0.0191 + 1.1786 x	0.0779	16.8279	10.8002	-	26.2198	418.4538	268.5643	-	651.9988
6	Y = 0.0962 + 1.1721x	0.2270	15.2653	9.6567	-	24.1313	386.4311	244.4540	-	610.8674
7	Y = 0.0544 +1.2062 x	0.2635	12.5980	7.8723	-	20.1589	418.4538	181.9038	-	465.8071

Table 12. Acute toxicity of acephate to Coimbatore population of *A. gossypii* by IRAC method No. 8

Generation	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
1	Y = 0.5868 + 1.1843 x	0.3597	5.3284	3.4823	-	8.1533	130.4890	85.2779	-	199.6692
2	Y = 0.9839 + 1.1060 x	0.0171	4.2756	2.7033	-	6.7608	131.2804	83.0233	-	207.5869
3	Y = 1.3180 + 1.0647 x	0.0270	2.8714	1.7823	-	4.6249	100.6699	62.5029	-	162.1437
4	Y = 1.2931 + 1.1215 x	0.0050	2.0193	1.2703	-	3.2099	59.1289	37.20499	-	94.0156
5	Y = 1.2143 + 1.1644 x	0.0426	1.7832	1.1348	-	2.8020	46.1158	29.3483	-	72.4631
6	Y = 1.1846 +1.1914 x	0.01277	1.5946	1.0114	-	2.5142	38.3156	24.3013	-	60.4117
7	Y = 1.2647 + 1.1803 x	0.0085	1.4615	0.9166	-	2.3304	36.1800	22.6902	-	57.6899

Table 13. Susceptibility index and rate of resistance decline in Coimbatore population of *A. gossypii*

Insecticide	Susceptibility Index		Rate of Resistance Decline	
	LC_{50}	LC_{95}	R	G
Thiamethoxam	3.05	3.24	-0.0692	14.45
Imidacloprid	3.94	2.42	-0.0851	11.75
Monocrotophos	3.12	5.59	-0.0706	14.16
Dimethoate	3.55	12.81	-0.0786	12.72
Methyl demeton	3.91	2.81	-0.0846	11.82
Acephate	3.65	3.61	-0.0803	12.45

Table 14. Acute toxicity of thiamethoxam to *A. gossypii* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = 1.7539 + 1.0757 x	0.4854	1.0414	0.6488	-	1.6715	35.2153	21.9405	-	56.5220
Bhavanisagar	Y = 1.9918 + 1.0390 x	0.0097	0.7859	0.4925	-	1.2544	30.1034	18.8620	-	48.0445
Dharapuram	Y = 1.5629 +1.1029 x	0.5319	1.3075	0.8074	-	2.1171	40.5397	25.0357	-	65.6447
Vaigaidam	Y =1.7348 + 1.1317 x	0.5256	0.7677	0.4948	-	1.1909	21.8103	14.0589	-	33.8353
Annamalai Nagar	Y =1.5391 + 1.1452 x	0.6947	1.0519	0.6699	-	1.6519	28.7278	18.2945	-	45.1111
Aduthurai	Y =1.7770 + 1.1290 x	0.0946	0.7157	0.4608	-	1.1116	20.4954	13.1962	-	31.8319
Kumbakonam	Y =1.9450 + 1.2061 x	0.0532	0.3412	0.2237	-	0.5204	7.8854	5.1698	-	12.0273
Srivilliputtur	Y =1.6021 + 1.1397 x	0.2420	0.9580	0.6154	-	1.4912	26.5826	17.0772	-	41.3786
Vellore	Y =15133 + 1.1377 x	0.4272	1.1608	0.7338	-	1.8363	32.4042	20.4839	-	51.2615

Table 15. Acute toxicity of imidacloprid to *A. gossypii* populations from different locations of Tamil Nadu

Location	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
Coimbatore	Y = 1.1220 + 1.1908 x	0.7636	1.8055	1.1698	-	2.7874	43.4310	28.1449	-	67.0656
Bhavanisagar	Y = 1.1274 + 1.2165 x	0.2720	1.5251	1.0037	-	2.3173	34.3099	22.5804	-	52.1323
Dharapuram	Y = 0.8494 + 1.2346 x	0.3952	2.3014	1.5395	-	3.4404	49.4703	33.0924	-	73.9539
Vaigaidam	Y = 1.0977 + 1.2377 x	0.5107	1.4215	0.9316	-	2.1689	30.3183	19.8705	-	46.2596
Annamalai Nagar	Y = 0.4835 + 1.3861 x	0.2010	1.8132	1.2566	-	2.6165	27.8722	19.3155	-	40.2194
Aduthurai	Y =1.3246 + 1.1378 x	0.2852	1.6991	1.1047	-	2.6133	47.4131	30.8269	-	72.9233
Kumbakonam	Y =1.8808 + 1.1974 x	0.0875	0.4028	0.2627	-	0.6176	9.5245	6.2117	-	14.6039
Srivilliputtur	Y =0.9747 + 1.2379 x	0.1677	1.7849	1.1828	-	2.6935	38.0495	25.2147	-	57.4174
Vellore	Y =0.7850 + 1.2624 x	0.1824	2.1828	1.4716	-	3.2376	43.8572	29.5681	-	65.0518

Table 16. Acute toxicity of monocrotophos to *A. gossypii* populations from different locations of Tamil Nadu

Location	**Regression equation**	**χ^2**	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
Coimbatore	Y = 1.2744 + 1.0439 x	0.2594	3.7057	2.3047	-	5.9585	139.4943	86.7551	-	224.2944
Bhavanisagar	Y = 1.0143 + 1.1004 x	0.2386	4.1879	2.6788	-	6.5470	130.8499	83.6994	-	204.5617
Dharapuram	Y = 1.0065 + 1.0753 x	0.0997	5.1728	3.2165	-	8.3190	175.1486	108.9085	-	281.6768
Vaigaidam	Y = 1.1575 + 1.1100 x	0.2498	2.8951	1.8333	-	4.5720	87.8113	55.6044	-	138.6727
Annamalai Nagar	Y = 0.5947 + 1.2310 x	0.0430	3.7899	2.5201	-	5.6996	82.1954	54.6552	-	123.6128
Aduthurai	Y = 1.1625 + 1.0765 x	0.2460	3.6709	2.3280	-	5.7886	123.8131	78.5179	-	195.2380
Kumbakonam	Y = 1.2727 + 1.1747 x	0.1965	1.4890	0.9239	-	2.3999	37.4237	23.2199	-	60.3161
Srivilliputtur	Y = 1.3090 + 1.0170 x	0.1920	4.2574	2.6280	-	6.8970	176.3912	10.8824	-	285.7565
Vellore	Y =0.9253 + 1.0843 x	0.0343	5.7260	3.5124	-	9.3348	188.2971	115.5023	-	306.9705

Table 17. Acute toxicity of dimethoate to *A. gossypii* populations from different locations of Tamil Nadu

Location	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
Coimbatore	Y = 1.2557 + 0.9293 x	0.0833	10.6924	6.3045	-	18.1342	629.6511	371.2309	-	1067.802
Bhavanisagar	Y =0.8880 +1.0018 x	0.1118	12.7210	7.7309	-	20.9319	557.7370	338.9532	-	917.7389
Dharapuram	Y = 0.8080 + 1.0020 x	0.1900	15.2649	9.1365	-	25.5043	668.857	400.3277	-	1117.509
Vaigaidam	Y = 1.3359 + 0.9323 x	0.0783	8.5156	5.0294	-	14.4185	494.9862	292.3407	-	838.1021
Annamalai Nagar	Y = 0.4081 + 1.1458 x	0.2544	10.1768	6.5509	-	15.8095	277.4593	178.6043	-	431.0294
Aduthurai	Y = 0.5372 + 1.0836 x	0.5765	13.1406	8.2923	-	20.8236	433.1771	273.3537	-	959.7991
Kumbakonam	Y = 0.1519 + 1.3644 x	0.0748	3.5761	2.4397	-	5.2418	57.4144	39.1694	-	84.1579
Srivilliputtur	Y = 0.3868 + 1.1372 x	0.1383	11.3957	7.3713	-	17.6175	318.5787	206.0704	-	492.5131
Vellore	Y =0.8579 + 0.9825 x	0.1667	16.4426	9.5951	-	28.1769	776.6293	453.2008	-	1330.8740

Table 18. Acute toxicity of methyl demeton to *A. gossypii* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = -0.6041 + 1.1943 x	0.3876	49.2606	32.2107	-	75.3529	1174.6270	767.8917	-	1796.8010
Bhavanisagar	Y = -0.4873 + 1.1527 x	0.6705	57.5844	37.5998	-	88.1909	1539.1710	1005.0040	-	2357.2310
Dharapuram	Y = 0.1495 + 1.0014 x	0.2707	69.7572	42.1086	-	115.5600	3062.8740	1848.8900	-	5073.9620
Vaigaidam	Y = -0.2125 + 1.1292 x	0.2554	41.3088	26.5360	-	64.3058	1182.2460	759.4526	-	1840.4130
Annamalai Nagar	Y = -0.8681 + 1.2465 x	0.7602	51.0042	33.9189	-	76.6955	1064.6590	708.0214	-	1600.9370
Aduthurai	Y = -0.5223 + 1.1524 x	1.0437	61.9998	40.4712	-	94.9805	1658.8340	1082.8260	-	2541.2480
Kumbakonam	Y = -0.7811 + 1.3888 x	1.0115	14.5422	9.6630	-	21.8850	222.3473	147.7454	-	334.6184
Srivilliputtur	Y = -0.7741 + 1.2213 x	0.2554	53.4164	35.2617	-	80.9182	1187.0780	783.6234	-	1798.2540
Vellore	Y =-0.4847 + 1.1548 x	0.2859	56.1874	36.5931	-	86.2739	1493.0880	972.4009	-	2292.5860

Table 19. Acute toxicity of acephate to *A. gossypii* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = 0.5868 + 1.1843 x	0.3597	5.3284	3.4823	-	8.1533	130.4890	85.2779	-	199.6692
Bhavanisagar	Y = 0.6417 + 1.2009 x	0.6360	4.2576	2.8054	-	6.4613	99.7404	65.7220	-	151.3670
Dharapuram	Y = 0.5703 + 1.1579 x	0.4004	6.6925	4.2957	-	10.4266	176.2598	113.1362	-	274.6029
Vaigaidam	Y = 0.8024 + 1.1486 x	0.2734	4.5128	2.9291	-	6.9527	122.0403	79.2121	-	188.0248
Annamalai Nagar	Y = 0.1431 + 1.3106 x	0.0688	5.0788	3.4556	-	7.4644	91.3682	62.1664	-	134.2871
Aduthurai	Y = 0.7426 + 1.1618 x	0.4482	4.6197	3.0175	-	7.0726	120.3591	78.6165	-	184.2656
Kumbakonam	Y = 0.9704 + 1.2452 x	0.0322	1.7222	1.1364	-	2.6100	36.0650	23.7974	-	54.6564
Srivilliputtur	Y = 0.5834 + 1.1791 x	0.5861	5.5670	3.6290	-	8.5399	138.2327	90.1114	-	212.0517
Vellore	Y =0.5358 + 1.1795 x	0.1818	6.0933	3.9582	-	9.3801	151.1629	98.1956	-	232.7010

Table 20. Resistance ratio of *A. gossypii* populations to different insecticides

Insecticides/ Location	Thiamethoxam		Imidacloprid		Monocrotophos		Dimethoate		Methyl demeton		Acephate	
	LC_{50}	LC_{95}	LC_{50}	LC_{95}	LC_{50}	LC_{95}	LC_{50}	LC_{95}	LC_{50}	LC_{95}	LC_{50}	LC_{95}
Bhavanisagar	2.30	3.82	3.79	3.60	2.81	3.50	3.56	9.71	3.96	6.92	2.47	2.77
Dharapuram	3.83	5.14	5.71	5.19	3.47	4.68	4.27	11.65	4.80	13.78	3.89	4.89
Vaigaidam	2.25	2.77	3.53	3.18	1.94	2.35	2.38	8.62	2.84	5.32	2.62	3.38
Annamalai Nagar	3.08	3.64	4.50	3.70	2.55	2.20	2.85	4.83	3.51	4.79	2.95	2.53
Aduthurai	2.10	2.60	4.22	4.98	2.47	3.31	3.67	7.54	4.26	7.46	2.68	3.34
Srivilliputtur	2.81	3.37	4.43	3.99	2.86	4.71	3.19	5.55	3.67	5.34	3.23	3.83
Vellore	3.40	4.11	5.42	4.60	3.85	5.03	4.60	13.53	3.86	6.72	3.54	4.19

Table 21. Acute toxicity of thiamethoxam to Coimbatore population of *A. devastans* by IRAC method No. 8

Generation	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
1	Y =4.1813 + 0.8713 x	1.2600	0.00087	0.00048	-	0.00158	0.06721	0.03693	-	0.12232
2	Y =4.1507 + 0.8538 x	1.5277	0.00078	0.00044	-	0.00137	0.04122	0.02337	-	0.07270
3	Y =4.2288 + 1.0041 x	0.8098	0.00059	0.00036	-	0.00096	0.02548	0.01553	-	0.04181
4	Y =4.1486 + 1.3024 x	0.5277	0.00045	0.00030	-	0.00067	0.00825	0.00556	-	0.01226

Table 22. Acute toxicity of imidacloprid to Coimbatore population of *A. devastans* by IRAC method No. 8

Generation	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
1	**Y =4.1519 + 0.8458 x**	0.7919	0.00101	0.00055	-	0.00185	0.08861	0.04814	-	0.16310
2	Y =4.2029 + 0.8631 x	0.7490	0.00084	0.00045	-	0.00156	0.06748	0.03630	-	0.12545
3	Y =4.3074 + 0.8775 x	0.3172	0.00062	0.00036	-	0.00106	0.04610	0.02662	-	0.07983
4	Y =4.0145 + 1.3695 x	0.3703	0.00052	0.00036	-	0.00076	0.00833	0.00575	-	0.01208

Table 23. Acute toxicity of monocrotophos to Coimbatore population of *A. devastans* by IRAC method No. 8

Generation	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
1	Y =1.5028 + 1.8370 x	1.4022	0.08013	0.06117	-	0.10497	0.62985	0.48082	-	0.82509
2	Y =1.6896 + 1.7880 x	1.2825	0.07103	0.05202	-	0.09698	0.59073	0.43266	-	0.80656
3	Y =1.8984 + 1.7109 x	1.0603	0.06498	0.04846	-	0.08715	0.59460	0.44337	-	0.79741
4	Y =2.0170 + 1.6903 x	0.2681	0.05818	0.04286	-	0.07899	0.54695	0.40289	-	0.74251

Table 24. Susceptibility index and rate of resistance decline in Coimbatore population of *A. devastans*

Insecticides	Susceptibility Index		Rate of Resistance Decline	
	LC_{50}	LC_{95}	R	G
Thiamethoxam	1.93	8.15	-0.0716	13.97
Imidacloprid	1.94	10.64	-0.0721	13.87
Monocrotophos	1.38	1.15	-0.0347	28.82

Table 25. Acute toxicity of thiamethoxam to *A. devastans* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Bhavanisagar	Y = 4.2519 + 0.8124 x	1.0063	0.00083	0.00044	-	0.00158	0.08824	0.04642	-	0.16774
Dharapuram	**Y = 4.1191 + 0.8797 x**	0.9500	0.00100	0.00057	-	0.00178	0.07433	0.04195	-	0.13168
Vaigaidam	Y = 4.2824 + 0.8400 x	1.2008	0.00072	0.00037	-	0.00139	0.06496	0.03335	-	0.12651
Aduthurai	Y = 4.2095 + 0.8899 x	1.1359	0.00075	0.00040	-	0.00142	0.05312	0.02821	-	0.10004
Kumbakonam	Y = 4.2641 + 1.0502 x	0.5755	0.00050	0.00031	-	0.00081	0.01850	0.01145	-	0.02989
Srivilliputtur	Y = 4.1930 + 0.8673 x	1.2759	0.00085	0.00047	-	0.00156	0.06717	0.03666	-	0.12305
Vellore	Y = 4.1202 + 0.8890 x	0.4898	0.00098	0.00055	-	0.00172	0.06917	0.03928	-	0.12183

Table 26. Acute toxicity of imidacloprid to *A. devastans* populations from different locations of Tamil Nadu

Location	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
Bhavanisagar	Y = 4.2141 + 0.8150 x	0.9529	0.00092	0.00048	-	0.00175	0.09604	0.05045	-	0.18284
Dharapuram	Y = 4.1471 + 0.8224 x	0.4620	0.00109	0.00059	-	0.00201	0.10894	0.05913	-	0.20069
Vaigaidam	Y = 4.2655 + 0.8021 x	0.4705	0.00082	0.00042	-	0.00160	0.09253	0.04755	-	0.18008
Aduthurai	Y =4.2891 + 0.8103 x	0.2744	0.00075	0.00038	-	0.00148	0.08080	0.04111	-	0.15877
Kumbakonam	Y = 4.2860 + 0.9525 x	0.4648	0.00056	0.00033	-	0.00094	0.02995	0.01784	-	0.05028
Srivilliputtur	Y = 4.2604 + 0.7757 x	0.2848	0.00090	0.00046	-	0.00175	0.11855	0.06080	-	0.23118
Vellore	Y = 4.1831 + 0.8277 x	0.3113	0.00097	0.00052	-	0.00182	0.09425	0.05039	-	0.17630

Table 27. Acute toxicity of monocrotophos to *A. devastans* populations from different locations of Tamil Nadu

Location	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
Bhavanisagar	Y = 1.2581 + 1.9778 x	1.1896	0.07797	0.06051	-	0.10046	0.52916	0.41070	-	0.68179
Dharapuram	Y = 1.5835 + 1.7548 x	0.1199	0.08850	0.06644	-	0.11790	0.76615	0.57513	-	1.02061
Vaigaidam	Y = 1.5140 + 1.8636 x	0.7884	0.07424	0.05686	-	0.09693	0.56659	0.43394	-	0.73977
Aduthurai	Y = 1.6545 + 1.7762 x	0.6575	0.07649	0.05798	-	0.10090	0.64518	0.48908	-	0.85109
Kumbakonam	Y = 1.9749 + 1.7477 x	0.6078	0.05380	0.03949	-	0.07335	0.47005	0.34491	-	0.64058
Srivilliputtur	Y = 1.3733 + 1.8978 x	1.4354	0.08148	0.06273	-	0.10584	0.59955	0.46156	-	0.77880
Vellore	Y = 1.7384 + 1.6474 x	1.1482	0.09550	0.06980	-	0.13060	0.95130	0.69540	-	1.30140

Table 28. Acute toxicity of dimethoate to *A. devastans* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = -0.8891 + 1.1558 x	1.0329	124.5106	80.2639	-	193.1489	3298.8880	2126.5790	-	5117.4500
Bhavanisagar	Y =-0.9103 + 1.1672 x	0.2060	115.8371	75.4069	-	177.9445	2972.8400	1935.2400	-	4566.7610
Dharapuram	Y = -0.7561 + 1.1052 x	0.7267	161.5030	99.2453	-	262.8156	4971.6380	3055.1240	-	8090.4030
Vaigaidam	Y = -0.8844 + 1.1551 x	1.3372	124.2365	80.0524	-	192.8075	3298.2070	2125.2170	-	5118.6160
Aduthurai	Y = -1.0851 + 1.2027 x	0.1870	114.621	75.6418	-	173.8112	2673.3570	1763.5950	-	4052.4260
Kumbakonam	Y = -0.0860 + 1.1090 x	0.1261	38.5430	24.2506	-	61.2588	1172.4990	737.7162	-	1863.5280
Srivilliputtur	Y = -0.8826 + 1.1596 x	0.7918	118.3212	76.3740	-	183.3071	3101.7060	2002.0910	-	4805.2660
Vellore	Y = -0.8490 + 1.1291 x	0.6858	163.4182	100.8180	-	264.8883	4779.8690	2948.856	-	7747.8000

Table 29. Acute toxicity of methyl demeton to *A. devastans* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = -0.6835 + 1.1083 x	1.1308	134.2762	84.9189	-	212.3215	4093.8570	2589.0350	-	6473.3260
Bhavanisagar	Y = -0.3491 + 1.0528 x	0.9540	120.4183	74.8819	-	193.646	4395.9130	2733.5880	-	7069.1150
Dharapuram	Y = -0.4162 + 1.0359 x	0.8036	169.2637	102.6037	-	279.2317	6553.7100	3972.7050	-	10811.5500
Vaigaidam	Y = -0.4435 + 1.0740 x	0.6449	117.0207	73.3662	-	186.6505	3979.0400	2494.6630	-	6346.6530
Aduthurai	Y = -0.5577 + 1.0936 x	0.6463	120.7656	76.3053	-	191.1312	3855.0230	2435.7830	-	6101.2000
Kumbakonam	Y = -1.7878 + 1.4716 x	0.4861	40.9672	28.6169	-	58.6474	537.2525	375.2887	-	769.1153
Srivilliputtur	Y = -0.6718 + 1.100 x	1.5478	142.3293	89.9589	-	225.1876	4444.5990	2809.1990	-	7032.0630
Vellore	Y = -0.6126 + 1.0741 x	0.5764	168.1297	103.8205	-	272.2737	5716.4580	3529.9280	-	9257.3840

Table 30. Acute toxicity of acephate to *A. devastans* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = 0.2467 + 0.9805 x	1.3104	70.4462	42.5679	-	116.5824	3353.2830	2026.2580	-	5549.3950
Bhavanisagar	Y = 0.5551 + 0.9356 x	1.3667	56.3425	32.9975	-	96.2035	3228.2230	1890.6390	-	5512.1180
Dharapuram	Y = 0.4452 + 0.9212 x	1.3091	87.9657	51.4521	-	150.3914	5368.7890	3140.2660	-	9178.8070
Vaigaidam	Y = 0.0983 + 1.0165 x	1.4832	66.4328	40.6851	-	108.4748	2758.4470	1689.3440	-	4504.1320
Aduthurai	Y = 0.1696 + 1.0095 x	1.1326	60.9616	37.1421	-	100.0567	2597.2970	1582.4560	-	4262.9640
Kumbakonam	Y = 0.2297 + 1.0496 x	0.1680	35.0521	21.4613	-	57.2495	1293.6600	792.2679	-	2112.8950
Srivilliputtur	Y = 0.1675 + 1.0031 x	1.5205	70.4462	39.9175	-	108.2526	2868.7410	1742.0220	-	4724.2090
Vellore	Y = 0.3868 + 0.9409 x	0.7735	79.9830	47.1008	-	135.8210	4479.3150	2637.8020	-	7606.4310

Table 31. Resistance ratio of *A. devastans* populations to different insecticides

Insecticides/ Location	Thiamethoxam		Imidacloprid		Monocrotophos		Dimethoate		Methyl demeton		Acephate	
	LC_{50}	**LC_{95}**	**LC_{50}**	**LC_{95}**	**LC_{50}**	**LC_{95}**	**LC_{50}**	**LC_{95}**	**LC_{50}**	**LC_{95}**	**LC_{50}**	**LC_{95}**
Coimbatore	-	-	-	-	-	-	3.23	2.81	3.28	7.62	2.01	2.59
Bhavanisagar	1.66	4.77	1.66	3.21	1.45	1.13	3.01	2.54	2.94	8.18	1.61	2.50
Dharapuram	2.00	4.02	1.95	3.64	1.64	1.63	4.19	4.24	4.13	12.20	2.51	4.15
Vaigaidam	1.44	3.51	1.46	3.10	1.38	1.21	3.25	2.81	2.86	7.41	1.89	2.13
Aduthurai	1.50	2.87	1.34	2.70	1.42	1.37	2.94	2.28	2.95	7.18	1.74	2.01
Srivilliputtur	1.70	3.63	1.61	3.96	1.51	1.28	3.07	2.64	3.47	8.27	2.01	2.22
Vellore	1.96	3.74	1.73	3.15	1.78	2.02	4.24	4.08	4.10	10.64	2.28	3.46

Table 32. Acute toxicity of thiamethoxam to *T. tabaci* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y =1.5098 + 1.2025 x	0.0988	0.0799	0.0525	-	0.1216	1.8642	1.2250	-	2.8371
Bhavanisagar	Y = 1.5177 + 1.2100 x	0.2823	0.0755	0.0493	-	0.1157	1.7270	1.1269	-	2.6470
Dharapuram	Y = 1.5620 + 1.1510 x	0.3830	0.0971	0.0635	-	0.1485	2.6076	1.7048	-	3.9886
Vaigaidam	Y = 1.5188 + 1.2165 x	0.2406	0.0727	0.0473	-	0.1117	1.6356	1.0646	-	2.5129
Aduthurai	Y = 1.5650 + 1.2115 x	0.0145	0.0685	0.0444	-	0.1056	1.5603	1.0117	-	2.4064
Kumbakonam	Y = 1.5186 + 1.2631 x	0.0242	0.0571	0.0366	-	0.0888	1.1446	0.7350	-	1.7822
Srivilliputtur	Y = 1.5050 + 1.1903 x	0.4262	0.0863	0.0569	-	0.1310	2.0798	1.3701	-	3.1572
Vellore	Y = 1.5764 + 1.1814 x	0.1728	0.0790	0.0514	-	0.1215	1.9507	1.2692	-	2.9981

Table 33. Acute toxicity of imidacloprid to *T. tabaci* populations from different locations of Tamil Nadu

Location	Regression equation	χ^2	LC_{50} (ppm)	Fiducial limits			LC_{95} (ppm)	Fiducial limits		
				LL		UL		LL		UL
Coimbatore	Y = 1.6532 + 1.2213 x	0.1349	0.0550	0.0368	-	0.0822	1.2223	0.8174	-	1.8277
Bhavanisagar	Y = 1.4924 + 1.3022 x	0.2543	0.0494	0.0337	-	0.0724	0.9054	0.6181	-	1.3264
Dharapuram	Y = 1.7417 + 1.1420 x	0.1099	0.0713	0.0455	-	0.1117	1.9650	1.2537	-	3.0799
Vaigaidam	Y = 1.5241 + 1.3050 x	0.3286	0.0461	0.0314	-	0.0677	0.8393	0.5712	-	1.2332
Aduthurai	Y = 1.6885 + 1.2561 x	0.6917	0.0433	0.0290	-	0.0647	0.8826	0.5905	-	1.3194
Kumbakonam	Y = 1.5876 + 1.3171 x	0.3635	0.0390	0.0263	-	0.0577	0.6914	0.4671	-	1.0234
Srivilliputtur	Y = 1.5233 + 1.2790 x	0.2500	0.0523	0.0354	-	0.0772	1.0105	0.6847	-	1.4913
Vellore	Y = 1.5901 + 1.2247 x	0.0671	0.0608	0.0405	-	0.0913	1.3406	0.8931	-	2.0123

Table 34. Acute toxicity of dimethoate to *T. tabaci* populations from different locations of Tamil Nadu

Location	**Regression equation**	χ^2	**LC_{50} (ppm)**	**Fiducial limits**			**LC_{95} (ppm)**	**Fiducial limits**		
				LL		**UL**		**LL**		**UL**
Coimbatore	**Y =-1.2723 + 1.2183 x**	0.3698	140.7500	92.5736	-	213.9978	3152.1850	2073.2450	-	4792.6180
Bhavanisagar	Y = -1.9048 + 1.3455 x	0.2017	135.3993	92.4607	-	198.2784	2259.9250	1543.2450	-	3309.4300
Dharapuram	Y = -0.9446 + 1.1357 x	1.2795	171.5809	106.3502	-	276.8213	4818.1210	2986.3940	-	7773.3510
Vaigaidam	Y = -1.4988 + 1.2747 x	0.3978	125.3475	83.7004	-	187.7171	2446.2090	1633.4490	-	3663.3760
Aduthurai	Y = -1.8940 + 1.3596 x	0.5410	117.6295	80.8865	-	171.0632	1906.9340	1311.2800	-	2773.1660
Kumbakonam	Y = -2.9775 + 1.6038 x	1.6528	94.1882	67.6537	-	131.1297	999.0683	717.6135	-	1390.9120
Srivilliputtur	Y = -0.9482 + 1.1422 x	0.4272	161.2918	101.4346	-	256.4712	4443.3860	2794.3960	-	7065.4570
Vellore	Y = -1.1484 + 1.1832 x	0.6496	157.1909	99.8269	-	247.5184	3860.4410	2451.6410	-	6078.7880

Table 35. Resistance ratio of *T. tabaci* populations to different insecticides

Insecticides/ Location	Thiamethoxam		Imidacloprid		Dimethoate	
	LC_{50}	**LC_{95}**	**LC_{50}**	**LC_{95}**	**LC_{50}**	**LC_{95}**
Coimbatore	1.40	1.63	1.41	1.77	1.49	3.16
Bhavanisagar	1.32	1.51	1.27	1.31	1.44	2.26
Dharapuram	1.70	2.28	1.83	2.84	1.82	4.82
Vaigaidam	1.27	1.43	1.18	1.21	1.33	2.45
Aduthurai	1.20	1.36	1.11	1.28	1.25	1.91
Srivilliputtur	1.51	1.82	1.34	1.46	1.71	4.45
Vellore	1.38	1.70	1.56	1.94	1.67	3.86

Table 36. Monitoring insecticide resistance in Coimbatore population of *A. gossypii*

Date	Thiamethoxam		Imidacloprid		Monocrotophos		Dimethoate		Methyl demeton		Acephate	
	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead /No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE
29.10.02	81/100	19.0±3.94	84/100	16.0±3.68	77/97	20.6±4.13	75/99	24.2±4.33	80/96	16.7±3.82	82/100	18.0±3.86
12.11.02	79/83	15.1±3.73	86/99	13.1±3.41	79/86	17.7±3.92	78/98	20.4±4.09	86/100	14.0±3.49	83/100	17.0±3.78
26.11.02	84/99	14.3±3.55	85/100	15.0±3.59	83/100	17.0±3.78	80/99	19.2±3.98	79/94	15.9±3.80	86/100	14.0±3.49
10.12.02	87/99	12.1±3.30	86/96	10.4±3.13	84/100	16.0±3.68	80/97	17.5±3.88	81/100	19.0±3.97	80/92	13.0±3.53
24.12.02	86/100	14.0±3.49	85/97	12.4±3.36	80/100	20.0±4.02	82/98	16.3±3.75	80/96	16.7±3.82	85/100	15.0±3.59
06.01.03	87/99	12.1±3.28	86/100	14.0±3.48	77/96	19.8±3.98	81/96	15.6±3.64	76/93	18.3±3.85	81/99	18.2±3.87
22.01.03	83/96	13.5±3.43	82/96	14.6±3.53	78/98	20.4±4.04	79/100	21.0±4.09	81/98	17.4±3.80	78/97	19.6±3.97
05.02.03	80/95	15.8±3.65	83/98	15.3±3.61	76/98	22.5±4.18	77/95	25.3±4.33	79/98	19.4±3.96	77/98	21.4±4.11
19.02.03	84/99	15.2±3.62	84/100	16.0±3.68	81/100	19.0±3.94	76/96	20.8±4.17	79/98	19.4±4.01	82/99	17.2±3.81
05.03.03	86/96	10.4±3.13	85/97	12.4±3.31	83/98	15.3±3.66	78/99	21.2±4.17	81/97	16.5±3.79	84/100	16.0±3.68
19.03.03	82/100	18.0±3.86	83/100	17.0±3.77	84/100	16.0±3.68	79/100	21.0±4.09	80/100	20.0±4.02	81/98	17.4±3.84
02.04.03	83/98	15.3±3.66	80/96	16.7±3.82	83/100	17.0±3.78	80/98	18.4±3.93	81/99	18.2±3.90	83/99	16.2±3.72
16.04.03	85/100	15.0±3.59	84/98	14.3±3.55	84/99	15.2±3.62	80/97	17.5±3.88	78/97	19.6±4.05	84/97	13.4±3.48
30.04.03	86/97	11.3±3.24	84/99	15.2±3.62	85/96	11.4±3.27	81/98	17.4±3.84	83/96	13.5±3.51	85/100	15.0±3.59

Table 37. Insecticide resistance in *A. gossypii* populations to various insecticides

Location	Thiamethoxam		Imidacloprid		Monocrotophos		Dimethoate		Methyl demeton		Acephate	
	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead /No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE
Bhavanisagar	80/98	18.4±3.88	82/98	16.3±3.71	75/96	21.9±4.13	79/99	20.2±4.03	78/100	22.0±4.16	84/100	16.0±3.68
Dharapuram	80/97	17.5±3.81	81/100	19.0±3.94	68/98	30.6±4.61	74/100	26.0±4.41	71/100	29.0±4.56	74/99	25.3±4.36
Vaigaidam	87/99	12.1±3.28	85/100	15.0±3.59	80/100	20.0±4.02	81/100	19.0±3.94	79/96	17.7±3.82	82/98	16.3±3.71
Annamalai Nagar	82/100	18.0±3.86	81/99	18.2±3.90	74/98	24.5±4.37	76/99	23.2±4.27	72/99	27.3±4.50	80/96	16.7±3.82
Trichy	39/49	20.4±5.82	41/50	18.0±5.49	40/49	18.4±5.59	38/50	24.0±6.10	40/48	16.7±5.44	39/47	17.0±5.54
Aduthurai	83/97	14.4±3.59	81/98	17.3±3.84	79/100	21.0±4.09	81/100	19.0±3.94	79/99	20.2±4.06	81/98`	17.4±3.84
Kumbakonam	91/100	9.0±2.88	89/100	11.0±3.15	87/99	12.1±3.30	87/98	11.2±3.20	86/98	12.2±3.33	88/100	12.0±3.27
Srivilliputtur	80/98	18.4±3.93	80/100	20.0±4.02	81/96	15.6±3.73	80/99	19.2±3.98	80/97	17.5±3.88	82/97	15.5±3.69
Vellore	85/98	13.3±3.44	83/99	16.2±3.72	71/100	29.0±4.56	69/100	31.0±4.65	73/99	26.3±4.45	81/100	19.0±3.94

Table 38. Monitoring insecticide resistance in Coimbatore population of *A. devastans*

Date	Dimethoate		Methyl demeton		Acephate	
	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE
24.10.02	71/91	21.9±4.37	78/98	20.4±4.09	78/96	18.8±4.00
07.11.02	72/90	20.0±4.24	78/94	17.0±3.90	73/89	17.9±4.09
21.11.02	82/98	16.3±3.75	84/100	16.0±3.68	74/89	16.9±3.99
05.12.02	84/99	15.2±3.62	77/95	18.9±4.04	81/96	15.6±3.72
14.12.02	81/96	15.6±3.72	77/89	13.5±3.64	81/93	12.9±3.49
02.01.03	77/93	17.2±3.94	79/96	17.7±3.92	81/98	17.4±3.84
19.01.03	81/100	19.0±3.94	78/98	20.4±4.04	81/99	18.2±3.87
31.01.03	79/100	21.0±4.09	81/100	19.0±3.94	82/100	18.0±4.16
14.02.03	80/96	16.7±3.46	83/99	16.2±3.72	80/98	18.4±3.93
28.02.03	81/100	19.0±3.94	80/97	17.5±3.88	81/99	18.2±3.90
14.03.03	83/99	16.2±3.72	82/98	16.3±3.75	84/100	16.0±3.68
28.03.03	84/98	14.3±3.55	81/100	19.0±3.94	81/98	17.4±3.85
11.04.03	84/100	16.00±3.58	84/100	16.00±3.68	82/97	15.46±3.69

25.04.03	80/100	20.00±4.02	80/98	18.37±3.93	83/100	17.00±3.78

Table 39. Insecticide resistance in *A. devastans* populations to various insecticides

Location	Thiamethoxam		Imidacloprid		Monocrotophos		Dimethoate		Methyl demeton		Acephate	
	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead /No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE
Coimbatore	89/100	11.0±3.14	87/99	12.1±3.29	80/99	19.2±3.98	-	-	-	-	-	-
Bhavanisagar	88/98	10.2±3.07	83/100	13.0±3.38	81/98	17.3±3.84	84/100	16.0±3.96	88/100	12.0±3.27	81/100	19.0±3.94
Dharapuram	84/99	15.1±3.62	83/98	15.3±3.66	76/100	26.0±4.35	45/60	25.0±5.64	46/58	20.7±5.36	45/53	15.1±4.96
Vaigaidam	84/95	11.6±10.91	87/99	12.1±3.29	80/99	19.2±3.98	73/87	16.1±3.96	72/91	20.9±4.28	77/93	17.2±3.93
Annamalai Nagar	82/100	18.0±3.86	82/100	18.0±3.86	78/100	22.0±4.16	76/95	20.0±4.13	77/98	21.4±4.17	83/99	16.2±3.72
Trichy	41/50	18.0±5.49	40/50	20.0±5.71	38/50	24.0±6.01	41/50	18.0±5.49	40/49	18.4±5.56	42/47	10.6±4.55
Aduthurai	83/100	17.0±3.78	82/100	18.0±3.86	79/100	21.0±4.09	78/99	21.2±4.13	79/98	19.4±4.01	81/98	17.4±3.84
Kumbakonam	94/100	6.0±2.39	93/100	7.0±2.56	87/100	13.0±3.38	89/100	11.0±3.14	91/98	7.1±2.62	90/97	7.2±3.64
Srivilliputtur	86/99	13.1±3.41	88/99	11.1±3.17	83/99	16.2±3.72	77/98	21.4±4.17	78/100	22.0±4.16	81/99	18.2±3.90
Vellore	81/100	19.0±3.94	80/100	20.0±4.02	76/100	24.0±4.29	71/99	28.3±4.55	74/100	26.0±4.41	78/99	21.2±4.13

Table 40. Monitoring insecticide resistance in Coimbatore population of *B. tabaci*

Date	Thiamethoxam		Imidacloprid		Monocrotophos		Acephate		Triazophos		Cypermethrin		Endosulfan	
	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE
21.02.03	84/100	16.0±3.68	83/100	17.0±3.78	76/100	24.0±4.29	78/100	22.0±4.16	69/100	31.0±4.65	65/100	35.0±4.79	73/100	27.0±4.46
28.02.03	86/100	14.0±3.48	87/100	13.0±3.38	79/100	21.0±4.09	79/100	20.0±4.02	67/100	33.0±4.73	70/100	30.0±4.61	75/100	25.0±4.35
13.03.03	83/75	16.0±4.26	65/75	13.3±3.95	61/75	18.7±4.53	61/75	20.0±4.65	51/75	32.0±5.42	50/75	33.3±5.48	59/75	21.3±4.76
27.03.03	61/75	18.7±4.53	60/75	20.0±4.65	59/75	21.3±4.76	59/75	18.7±4.53	53/75	29.3±5.29	54/75	28.0±5.22	58/75	22.7±4.87
18.04.03	42/50	16.0±5.24	41/50	18.0±5.49	37/50	26.0±6.27	37/50	26.0±6.26	34/50	32.0±6.66	33/50	34.0±6.77	38/50	24.0±6.10
02.05.03	43/50	14.0±4.96	41/50	18.0±5.49	36/50	28.0±6.41	39/50	22.0±5.92	33/50	34.0±6.77	34/50	32.0±6.66	40/50	20.0±5.71
16.05.03	41/50	18.0±5.49	43/50	14.0±4.96	37/50	26.0±6.27	38/50	24.0±6.10	37/50	26.0±6.27	33/50	34.0±6.77	36/50	28.0±6.41

Table 41. Insecticide resistance in *B. tabaci* populations to various insecticides

Location	Thiamethoxam		Imidacloprid		Monocrotophos		Acephate		Triazophos		Cypermethrin		Endosulfan	
	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE	No. dead / No. tested	% survival ± SE
Bhavanisagar	43/50	14.0±4.96	42/50	16.0±5.24	38/50	24.0±6.10	39/50	22.0±5.92	41/50	18.0±5.49	39/50	22.0±5.92	40/50	20.0±5.71
Dharapuram	39/50	22.0±5.92	38/50	24.0±6.10	36/50	28.0±6.41	37/50	26.0±6.27	37/50	26.0±6.27	35/50	30.0±6.55	39/50	22.0±5.92
Vaigaidam	41/50	18.0±5.49	40/50	20.0±5.71	39/50	22.0±5.92	38/50	24.0±6.10	38/50	24.0±6.10	40/50	20.0±5.71	41/50	18.0±5.49
Annamalai Nagar	40/50	20.0±5.71	41/50	18.0±5.49	38/50	24.0±6.10	37/50	26.0±6.27	40/50	20.0±5.71	37/50	26.0±6.27	39/50	22.0±5.92
Trichy	39/50	22.0±5.92	38/50	24.0±6.10	40/50	20.0±5.71	41/50	18.0±5.49	39/50	22.0±5.92	38/50	24.0±6.10	41/50	18.0±5.49
Kumbakonam	45/50	10.0±4.29	46/50	8.0±3.88	43/50	14.0±4.96	44/50	12.0±4.64	44/50	12.0±4.64	43/50	14.0±4.96	45/50	10.0±4.29
Aduthurai	40/50	20.0±5.71	39/50	22.0±5.92	40/50	20.0±5.71	39/50	22.0±5.92	41/50	18.0±5.49	38/50	24.0±6.10	40/50	20.0±5.71
Srivilliputtur	39/50	22.0±5.92	40/50	20.0±5.71	39/50	22.0±5.92	41/50	18.0±5.49	40/50	20.0±5.71	38/50	24.0±6.10	41/50	18.0±5.49
Vellore	40/50	20.0±5.71	42/50	16.0±5.24	35/50	30.0±6.55	38/50	24.0±6.10	39/50	22.0±5.92	36/50	28.0±6.41	38/50	24.0±6.10

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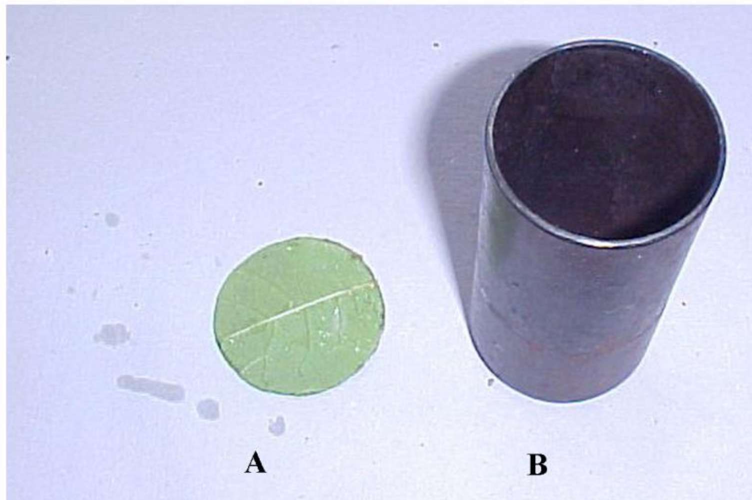

Plate 6. Cork borer (B) for taking leaf discs (A) (45mm dia)

Plate 7. Adult of *B. tabaci*

Plate 2. Apterous adult of *A. gossypii*

Plate 3. Early third instar nymph of *A. devc*

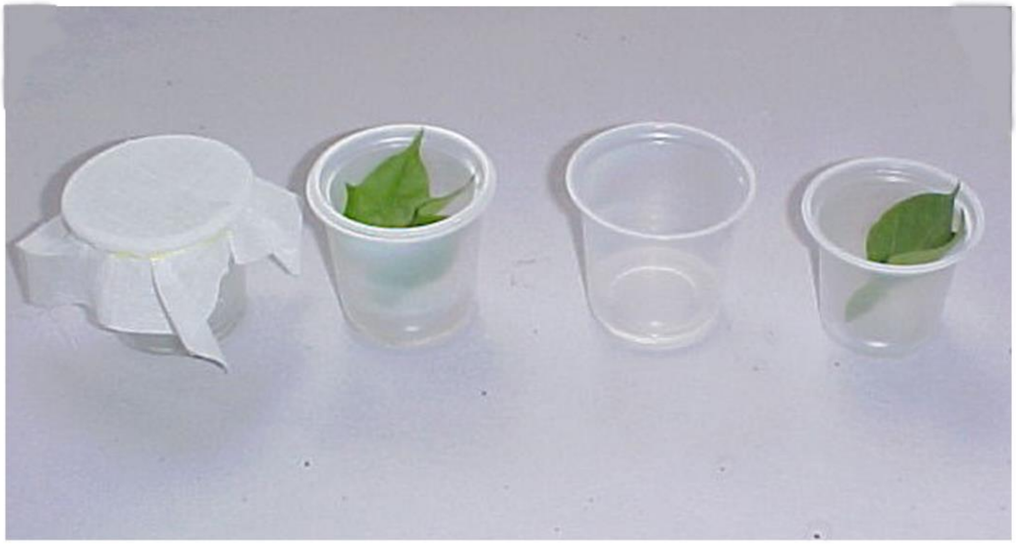

Plate 4. IRAC method No.8 bioassay setup for aphid and leafhopper

Plate 1. Mass culturing of test insects

Plate 9. Second instar nymph of *T. tabaci*

Plate 10. Bioassay setup for *T. tabaci*