MONITORING ACARICIDE RESISTANCE IN TWO SPOTTED SPIDER MITE, *Tetranychus urticae* Koch (Acari : Tetranychidae) INFESTING TOMATO

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DEDICATED

TO

MY FAMILY

AND

CHAIRPERSON

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
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CERTIFICATE

This is to certify that the thesis entitled **"Monitoring acaricide resistance in two spotted spider mite, *Tetranychus urticae* Koch (Acari : Tetranychidae) infesting tomato"** submitted by **Mr. RANJEETH KUMAR, B.V.**, in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRICULTURAL ENTOMOLOGY** of the University of Agricultural Sciences, Bangalore is a record of research work done by him during the period of his study in this university under my guidance and supervision and the thesis has not previously formed the basis of the award for the degree, diploma, associateship, fellowship or other similar titles.

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THESIS ABSTRACT

Investigations were carried out to determine the base-line values for susceptibility of laboratory population of *T. urticae* to selected acaricides, to monitor the level of resistance to acaricides in *T. urticae* populations on tomato from Bangalore and Kolar districts and field evaluation of newer acaricidal molecules against this mite pest on tomato.

The susceptibility of laboratory population of *T. urticae* to wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite increased over successive generations (from 5th to 38th generation). The base line values for the susceptible laboratory population at the 38th generation were 114 ppm for wettable sulphur, 0.1 ppm each for dicofol, abamectin, fenazaquin & diafenthiuron and 0.3 ppm for propargite.

The level of resistance to wettable sulphur in *T. urticae* populations from tomato crop in Bangalore and Kolar district was low to moderate as the resistance ratio ranged from 3.2 to 38.1. For dicofol, resistance was high in both Bangalore (767 to 3690 folds) and Kolar districts (500 to 6491 folds). For abamectin the resistance was low in Kolar district (RR <10). For diafenthiuron resistance level was moderate in both Bangalore and Kolar districts (RR 14-37 and 18-47, respectively). However, the resistance level increased to higher levels of 67 and 79 folds during December 2007 and February 2008. For fenazaquin, mite populations from Bangalore and Kolar districts showed progressive resistance from low to moderate level (RR 5 to 32) as the tomato cropping season advanced, but resistance was high (168 - 249 folds) in Vadagur of Kolar district beyond September. Low levels of resistance (4-12 folds) to propargite in Bangalore and Kolar districts during kharif increased to a moderate level during December 2007 and February 2008.

Field evaluation of newer acaricides against *T. urticae* in Vadagurof Kolar district revealed better effectiveness with milbemectin (3.75 g a.i./ha), fenazaquin (125 g a.i./ha), propargite (570 g a.i./ha), chlorfenapyr (75 g a.i./ha) and fenpyroximate (30 g a.i./ha), which accounted for 70% reduction in the egg population of spider mite. Chlorfenapyr, fenazaquin and propargite were superior in bringing down the population of active stages by 75 to 91%. However, against mixed stage population, milbemectin and fenazaquin causing 82-83% reduction were significantly more effective followed by propargite, chlorfenapyr and fenazaquin causing 70-76% reduction. The effect of diafenthiuron (450 g a.i./ha), abamectin (6 g a.i./ha) and mineral oil 1% was moderate recording 61 - 66% reduction.

Signature of the Student | Signature of the Major Advisor

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INTRODUCTION

I. INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.), a member of the family Solanaceae is one of the most important and widely grown vegetable crops in both tropics and subtropics in the world. It is said to be a native of tropical America (Thompson and Kelly, 1957) from where, it spread to other parts of the world in the 16^{th} century and became popular in India during the last six decades. Tomatoes are a good source of vitamins such as vitamin 'A', vitamin 'B' (Thiamin), vitamin 'B_2' (Riboflavin) and vitamin 'C' (Ascorbic acid) and other minerals, which makes them a nutritive and valuable vegetable. Tomato is cultivated in an area of 3.989 million hectares with a production of 108.50 million tonnes in the world with a productivity of 27202 kg/ha and in India, it is cultivated in 5.2 lakh hectares with production of 74.2 lakh tonnes with a productivity of 14269 kg/ha (Anonymous, 2004a). Karnataka is a major producer of tomato in India, where it occupies an area of 29474 hectares with a production of 237365 tonnes, in which summer crop accounts for an area of 7595 hectares with a production of 53905 tonnes (Anonymous, 2004b). Bangalore and Kolar districts contribute nearly 35 per cent of total tomato production in Karnataka.

A wide range of insect and mite pests attack tomato and form the major limiting factor for its successful cultivation. Due to insect pests, up to 50-80% losses have been recorded on tomato in Bangalore (Tewari and Krishnamoorthy, 1984). Tomato is attacked by several species of mites, such as *Tetranychus urticae* Koch, *T. cucurbitae etc.* (Acari : Tetranychidae) (Butani, 1975) and *Aceria lycopersici* (Acari: Eriophyidae) in India (Singh, 1970). Two-spotted spider mite, *T. urticae* is one of the mite pests reported as serious on many vegetable crops like tomato, brinjal, okra, French bean *etc.* This species also damages pumpkin, alfalfa, cotton, *Hibiscus*, cucurbitaceous crops *etc.* (Meyer and Rodriguez, 1966). *T.*

urticae recently has been observed to be causing appreciable damage on tomato fields in and around Bangalore and reported to multiply rapidly during summer months (Anonymous, 2004c and Aji, 2005). It is also reported to be serious in Africa and other parts of the world where tomato is cultivated as a major vegetable crop (Anonymous, 2003a). The intervention of the farmers by using acaricides has been a common strategy and conventional acaricides like wettable sulfur, dicofol and newer molecules like fenazaquin are widely used for the control of this mite.

Conventional pesticides such as chlorinated hydrocarbons; organophosphates, carbamates and pyrethriods were successful in controlling insect pests during the past five decades, thereby minimizing losses in agricultural yields. Unfortunately, many of these chemicals are harmful to man and the beneficial organisms and cause ecological disturbances. Although considerable efforts have been made to minimize the adverse environmental impact of pesticides on the health of human population and domestic animals, still there is great demand for safer chemicals which selectively affect the harmful pests, sparing beneficial insects and other non-target organisms.

Phytophagous mites proliferate particularly in situations in which non-specific insecticides are applied in concentrations that eliminate natural mite predators without harming the pest mites, and their short development cycle tends to favour rapid development of pesticide-resistant populations by removing unfavourable genes for their existence (Dekeyser and Downer, 1994). The spider mites are one of the most serious arthropod pests in agriculture not only because they cause severe damage on crops, but intensive use of synthetic pyrethroids and other broad-spectrum non-selective pesticides have recently caused another problem, the resurgence of mites.

The management of *T. urticae* has depended primarily and heavily on the use of acaricides. Several acaricides such as dicofol, wettable sulphur, fenazaquin, propargite, diafenthiuron, and abamectin have been reported to be very effective in controlling tomato mites (Beers *et al.*, 1998 ; Andrei, 2005). The reliance on this single approach has led to ever-increasing cost, decreased effectiveness and eventual breakdown of control methods. In spite of heavy use of insecticides still it has not become possible to manage the pest adequately because of the development of resistance.

Resistance to pesticides is an evolutionary phenomenon brought about by intensive "natural selection" of the pest after continuous massive application of chemicals. Spider mites are the most conspicuous group, to have not only survived but also prospered through their ability to acquire resistance to the chemicals employed for their control. The reports from different parts of the world indicate that resistance to pesticides in mites of the family Tetranychidae is wide spread and covers almost all major classes of insecticides or acaricides (Young *et al.*, 2004). Resistance development by *T. urticae* to pesticidal chemicals namely dicofol, monocrotophos, methomyl, profenophos, dichlorvos and dimethoate, especially on vegetable crops has been reported sporadically in India and elsewhere (Shaila, 1999). Tomato is one such vegetable crop which requires application of acaricidal chemicals against *T. urticae* occasionally, but at times applied indiscriminately.

The records of resistance development to synthetic chemicals in *T. urticae* in India are either scanty or sporadic. *T. urticae* might have developed resistance to frequently used pesticidal chemicals because of its intrinsic abilities. To minimize this risk of resistance, alternative use of newer acaricidal molecules like fenpyroximate, buprofezin, fenazaquin, abamectin, diafenthiuron, propargite, milbemectin, chlorfenapyr *etc.* is often suggested as this would slow down the rate of development of resistance.

Keeping this in view, the present investigations on the acaricidal resistance in two spotted spider mite, *T. urticae* infesting tomato were undertaken with the following broad objectives.

1. Establishing base-line values for susceptibility of *T. urticae* infesting tomato to acaricides namely, wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite.

2. Assessment of resistance to acaricides in *T. urticae* populations from Bangalore and Kolar districts.

3. Evaluation of newer acaricidal molecules against *T. urticae* infesting tomato.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Investigations on pesticide resistance in *Tetranychus urticae* Koch infesting tomato were undertaken during 2006-2008 at the Department of Agricultural Entomology, University of Agricultural Sciences, G.K.V.K, Bangalore. The literature pertaining to development of resistance in *Tetranychus urticae* to synthetic chemicals *viz.*, dicofol, wettable sulphur, propargite, fenazaquin, diafenthiuron and abamectin, especially on tomato are very few. However, the available information on development of resistance to acaricides in mites infesting various other crops is reviewed hereunder.

Two-spotted spider mite, *T. urticae* is one of the mite pests reported as serious on many vegetable crops like tomato, brinjal, okra, French bean *etc.* This species also damages pumpkin, alfalfa, cotton, *Hibiscus*, cucurbitaceous crops *etc.* (Meyer and Rodriguez, 1966).

2. Occurrence of pesticide resistance in spider mite and assessment of level of resistance

2.1. Resistance to organochlorines

Iacob *et al.* (1980) monitored the development of resistance to dicofol in *Tetranychus urticae* for four years in a commercial green house. It was found that increase in resistance was 100 to 1000 folds in terms of LD and LT values.

Dennehy and Granett (1984a) observed 573 folds resistance in *T. urticae* and 160 folds resistance in *T. pacificus* to dicofol on cotton. The LC_{50} value for susceptible *T. pacificus* was 38 ppm, while for resistant strain it was 6513 ppm. *T. turkestani* was more susceptible to dicofol with a lower LC_{50} value of 11 ppm.

Susceptibility in the populations of *P. ulmi* and *T. urticae* from New York apple orchards to dicofol was estimated during 1985-86 with a whole-plant residual bioassay by Dennehy *et al.* (1988). Nine of *P. ulmi* populations collected throughout the state in 1985 had <80% mortality in 1000 mg/g dicofol (discriminating concentration) bioassays and were designated as resistant. *T. urticae* populations evaluated in 1985 were generally more susceptible to dicofol than that of the *P. ulmi* populations. Seven of ten *T. urticae* populations tested had no survivors in any 1000-mg/g bioassays. In 1986, 12 of 13 *P. ulmi* populations evaluated from the Hudson Valley were susceptible to dicofol. Pressured with dicofol, two isolated populations of *T. urticae* collected from orchards located more than 100 km apart illustrated the change in population response that occurred as a result of dicofol treatments. After one year of dicofol selection, both cultures were equally and highly resistant to dicofol. Probit analysis of the response of the two pressured cultures and two susceptible cultures indicated >1000-folds resistance to dicofol residues, whereas susceptible mites were approximately affected by residual or topical exposure to dicofol, resistant mites (possessing a >1000-folds resistance to residual exposure) were <15-folds resistant to topical contact with dicofol. Field trials conducted at orchard locations with *P. ulmi* populations resistant or susceptible to dicofol illustrated that resistance resulted in reduced efficacy of dicofol treatments.

Pree and Wagner (1987) observed the occurrence of 15 folds resistance to dicofol in a laboratory-selected population of European red mite, *Panonychus ulmi*.

The selective effect of dicofol application on resistant or susceptible population of *T. urticae* on apple in New York was studied by Dennehy *et al.* (1991). It was found that dicofol resistance was incompletely dominant under field conditions, in contrast with its recessive inheritance in laboratory bioassay. LC_{50} values were 2 to 4 times higher on exposure to discontinuous residues of dicofol than on continuous residues.

Cheng and Pan (1994) recorded a higher LC_{50} value of 1791.43 ppm for dicofol in a population of *T. urticae,* while lower LC_{50} values of 237.93, 830.98 and 732.32 ppm were observed in the population of *T. cinnabarinus* from Danzhou, Yueyang and Sheyang, respectively.

Samples of the two spotted spider mite *T. urticae* were collected from two locations of Turkey and reared in the laboratory on bean plants. The LC_{50} values obtained for the two populations were 18 and 16 ppm (Tamex *et al.*, 1996).

Cross-resistance of dicofol resistant *T. urticae* to 21 pesticides was studied by Fergusson - Kolmes *et al.* (1991). Dicofol resistant population showed strong positive cross-resistance to amitraz, bromopropylate and chlorobenzilate. Moderate negative cross-resistance was observed for chlorpyrifos. Estrada-Cotero and Sanchez-Galvez (1990) studied the toxicity of acaricides, chlorobenzilate, endosulfan, dicofol and phosalone to field collected populations, the LC_{50} values were 430.19, 13180.91, 2804.25 and 87582.87 ppm, respectively. Levels of resistance were calculated in comparison with the known susceptible population and the resistance was highest for dicofol 46, 73,750ppm.

Laboratory and field studies were conducted to characterize the interface between citrus rust mite *Phyllocoptruta oleivora* (Ashmead) and the acaricide dicofol. Direct and residual (continuous and discontinuous residues) contacts of dicofol on susceptible (S) and dicofol-resistant (R) strains of the mite were evaluated. The decay in biological activity of different formulations of dicofol was also measured in both the strains. Differences between S and R strains were less pronounced in direct contact than in residual contact with dicofol. When dicofol was used at high concentrations in residual bioassays (500-1280 µg a.i. /ml of water [ppm]), the expression of resistance was very poor on fresh residues of dicofol. However, as residues decayed substantially greater mortality of the S strain than the R strain was observed. Field studies showed that dicofol on citrus fruits became biologically inactive to rust mite relatively faster, both S and R strains survived completely when transferred to a six day residue. The formulation of dicofol had a significant effect on the rate of decay and biological activity. Differences in the rate of decay observed in bioassays were consistent with the field performance of dicofol in controlling citrus rust mite (Dennehy *et al.*, 1995).

Shaila (1999) observed high level of resistance to profenophos, monocrotophos, dimethoate, dichlorvos (14 to 33 folds) compared to 4.3 folds resistance to dicofol in *T. urticae* populations from open field cultivated rose.

Resistance to dicofol in carmine spider mite, *Tetranychus cinnabarinus* was investigated by Fatih Dagli and Irfan Tunc (2001). Higher resistance levels were detected by leaf residual bioassays than by topical bioassays in almost all the populations of *T. cinnabarinus* examined from Antalya, Turkey. The resistance level at LC_{95} was 17.5-folds in topical bioassays, but it was 58.9-folds in residual bioassays for the population collected from greenhouses in the Topcular district. There were differences of resistance levels at LC_{95} ranging between 2.6- and 23.9-folds in topical bioassays and between 5.0- and 58.9-folds in residual bioassays in populations collected from greenhouses. Further they observed that resistance to dicofol as indicated by topical and residual bioassays increased to 19.7 and 100.7 folds, respectively in a colony from the laboratory strain of *T. cinnabarinus* selected with dicofol alone for 16 cycles. However, dicofol resistance had increased to 19.4 and 52.0 folds in another colony selected in rotation with dicofol and tetradifon for six and eight cycles, respectively. The changes in resistance to dicofol was monitored 5 months after the selection was ceased, in the colony selected for dicofol alone resistance decreased to 11.7-99.1 folds and in the colony selected in rotation with dicofol and tetradifon, it decreased to 10.8-15.8-folds.

Samples of spider mite populations collected from ten rose houses were tested for resistance to parathion, tetradifon and dicofol. Despite the fact that for a period of 7 years tetradifon and dicofol had not been used, resistance to these acaricides was still present in most populations. Reversion to susceptibility in practice was apparently very slow and excluded the possibility of a rotational spray system (Overmeer *et al.*, 1975).

Sridhar and Jhansi Rani (2007) recorded 2-3 folds resistance to dicofol and 2 to 12 folds resistance to wettable sulphur in *T. urticae* populations from polyhouse roses in Delhi, Pune, Bangalore and Hosur (Tamil Nadu).

2.2. Resistance to organophosphates and carbamates

Dittrich (1969) reported resistance development in *T. urticae* to parathion and oxydemeton methyl with LC_{50} values of 4600 and 640 ppm, respectively, while the LC_{50} values for the susceptible population were, 87.40 and 10.56 ppm, respectively. Morse and Croft (1981a & b) observed comparable level of resistance development to azinphosmethyl in a susceptible population of *T. urticae* after 22 generations. When limited number of resistant mites was hybridized with susceptible population, they incorporated the resistance rapidly at comparable rates when selected for 5 - 8 generations. The LC_{50} of the initial susceptible population was 0.03029% and that after selection was 0.61808%. The initial LC_{50} of the resistant strain used in this experiment was 0.03029% and the same after hybridization with susceptible strain had the LC_{50} of 0.45876%.

Susceptibility levels to four acaricides omethoate, oxydemeton methyl, ethion and propargite in field collected adult females was determined by LC_{50}. The values were 3109.72, 11552.66, 5830.94 and 1464.18 ppm, respectively. Levels of resistance were calculated by comparison with the known susceptible population. The resistance values were high for omethoate (586739 ppm) and propargite (73209.00 ppm) (Estrada-Cotero and Sanchez-Galvez, 1990).

Hurkova *et al.* (1983) reported resistance to thiometon in populations of *T. urticae* from commercial green houses during 1974-76, which ranged from 1.6 to 19.6

folds, the resistance to thiometon and fenitrothion in *P. ulmi* from apple in Bohemia ranged from 8.5 to 68.0 and 10.5 to 102.8 folds, respectively.

LC_{50} values for malathion resistant laboratory strain, susceptible laboratory strain and *T. urticae* mites from fields of apple and peach orchards were 206 ppm, 284 ppm, 166 ppm and 33 ppm, respectively (El-Din, 1992).

Susceptibility in *T. urticae* from a rose crop to acaricides was compared with mites from a forest ecosystem. Resistance to dimethoate, propargite, naled and mevinphos in mites from roses ranged from 1.8 - 5.2 times the value in mites from forests. The mites were relatively tolerant to dimethoate and naled (Souza - Filho *et al.*, 1994). In another study conducted by Takematsu *et al.* (1994), *T. urticae* from rose showed 4.08 folds resistance to dimethoate, propargite, naled and mevinphos. Herron *et al.* (1995) observed increase in resistance to acaricides over a period of time. *T. urticae* showed more stable resistance of 15 folds in 1978-87 and increased to 54 folds in 1990. In a study where acaricide resistant strains of *T. urticae* were monitored from 1976-1995, the mite was resistant to all organophosphates tested, demeton-S-methyl, dimethoate, parathion, profenophos and monocrotophos with maximum resistance factor of 650x, 750x, 78x, 15x and 40x, respectively. Resistance peaked in 1995 at levels >100 folds for profenophos and >400 folds for monocrotophos (Herron *et al.*, 1998).

With regard to resistance to carbamate pesticides, El-Din (1992) reported that LC_{50} values for four strains of *T. urticae* to Lannate (methomyl) in resistant and susceptible populations collected from peach and apple trees were 7.4 ppm, 2990 ppm, 2330 ppm and 604 ppm, respectively.

2.3. Resistance to other groups of pesticides

Keena and Granett (1990) collected the populations of *T. urticae* and *T. pacificus* from two sites of San Soaquin Valley. The most susceptible population of *T. urticae* to propargite was collected from site Ugarov and that of *T. pacificus* was from site Nikolski, which had LC_{50} value 8 times higher than that for the *T. urticae* colony, indicating that *T. pacificus* might have a natural tolerance to propargite. The estimated LC_{98}, LC_{99}, and $LC_{99.99}$ values of propargite for the susceptible field-collected European red mite, *P. ulmi* were 0.036, 0.045, and 0.869% a.i. respectively. However, the observed mortalities ($x\% \pm SE$) for the greenhouse colony at the LC_{98} (96.9 + 0.78) and LC_{99} (97.6 ± 0.70) were slightly lower than predicted. Based on these results, the LC_{99} of propargite, 0.045% a.i. was selected as the discriminating concentration. Any test strain giving mortality below 98% was suspected of having some resistant individuals (Kabir *et al.*, 1993).

Souza-Filho *et al.* (1994) carried out an experiment to study the susceptibility of *T. urticae* collected from grapes in Polardo Sul, Brazil to some acaricides in comparison with *T. urticae* from a natural forest. The mites collected from grapes were upto 1.24 times more resistant to propargite. Cheng and Pan (1994) conducted laboratory tests (using glass slide dip method) on *T. urticae* to determine the LC_{50} values for four populations. The Honan population had the values of 8104.01 ppm for propargite. The LC_{50} values of propargite for Danzhou, Yueyang and Sheyang populations were 804.64, 112.03 and 732.32pp, respectively. Sato *et al.* (1994) studied the resistance of two spotted spider mite to various acaricides on strawberry and from forests. The LC_{50} values of propargite and other pesticides for mite populations from strawberry were 0 to 54 times more than that of the mites from the forests.

Laboratory selections for resistance and susceptibility to fenpyroximate were performed in a population of two-spotted spider mite, *T. urticae* (green-form), collected from a commercial strawberry field in the State of Sao Paulo, Brazil by Sato *et al.* (2004). After five selections for resistance and three selections for susceptibility, the resistance ratios (R/S) at the LC_{50} and LC_{95} reached 2,910 and 2,280, respectively. Studies on field populations of *T. urticae* from apple orchards in Akita showed resistance to fenpyroximate and pyridaben. A population selected seven times for resistance to fenpyroximate showed high resistance to pyridaben (LC_{50} > 533 ppm) (Funayama and Takahashi, 1995).

The influence of fenbutatin oxide on organotin resistant two spotted mite, *T. urticae* was determined by Herron *et al.* (1994) and a high level of resistance of >1500 folds was confirmed in the field strain. But the level of cyhexatin resistance was only 9.8 folds.

Edge and James (1982) reported the development of resistance by *T. urticae* to cyhexatin in apple orchard. The resistance was compared with a susceptible reference strain using Potter's spray tower technique. It was observed that the field population showed 7.5-folds resistance. Four years later, Edge and Jammes (1986) observed that in a population from apple and pear orchards the resistance did not exceed 15 folds. Keena and Granett (1987) tested 20 populations of *T. urticae* from orchards for cyhexatin resistance. No much difference was observed in the LC_{50} values for these populations. Souza-Filho *et al.* (1994) reported that the mites from grapes were 1.24 folds resistant to cyhexatin than the mites from the forests. LC_{50} values to adult females of two populations of *P. ulmi* were 0.03 - 0.126, 0.03-0.18 and 0.19 ppm of pyridaben, fenpyroximate and fenbutatin oxide, respectively. *T. urticae* sampled from pear orchards were tested for susceptibility to cyhexatin and fenbutatin oxide by Tongyantian *et al.* (1992). Maximum difference in susceptibility (LC_{50}) to cyhexatin between colonies was 38 folds and to fenbutatin-oxide the maximum difference was 478 folds. The susceptibility of *T. urticae* to cyhexatin was studied using mites collected from strawberries. The mites from strawberries were 0 to 5.4 times more resistant to cyhexatin than mites from the forest (Sato *et al.*, 1994). Souza-Filho *et al.* (1994) studied the susceptibility of *T. urticae* collected from a rose crop to cyhexatin in comparison with mites from a forest. The mites from roses were 1.8-5.2 folds more resistance than the mites from the forest. Washington State University established a Tree Fruit Research & Extension Center to mitigate the problem of resistance and demonstrated that populations of spider mites in tree fruits in Washington had then regained susceptibility to cyhexatin (Young *et al.*, 2006).

Kimura and Kushita (1994) reported that LC_{50} values to adult females of two populations of *P. ulmi* were 0.03-0.126ppm, 0.03-0.18ppm and 0.19ppm of pyridaben, fenpyroximate and tebufenpyrad respectively, while for *T. urticae*, the LC_{50} values were 24.65, 203.03, 2.69, 15.61 and 7.01ppm, respectively.

Cheng and Pan (1994) conducted laboratory tests on *T. urticae* collected from apple trees and the LC_{50} of amitraz was 4139.04 ppm.

A field colony of *T. urticae* was selected successively for 20 generations with pyridaben to produce the PR-20 strain. Resistance and multiple resistance levels of the PR-20 strain to 15 acaricides were determined using a spray bioassay. The PR-20 strain was extremely resistant to pyridaben (resistance ratio [RR] = 240]. The strain exhibited extremely strong resistance to fenpyroximate (RR = 373) and acinathrin (RR = 329) and a strong resistance to benzoximate (RR = 84). A resistant ratio of 10–40 was observed with abamectin, fenazaquin, fenbutatin oxide, fenpropathrin, and tebufenpyrad. The PR-20 strain showed low levels of resistance (RR < 10) to azocyclotin, bromopropylate, chlorfenapyr, dicofol, milbemectin, and propargite. Synergist experiments with different metabolic inhibitors revealed that piperonyl butoxide (PBO), a mixed function oxidase (MFO) inhibitor, had the greatest effect on pyridaben resistance. PBO significantly caused pyridaben resistance in the PR-20 strain to drop to the full susceptibility level of the susceptible strain(S). However, there was no significant difference in MFO activities measured between the susceptible and the PR-20 strains. It was suggested to use acaricides with low multiple resistance or PBO in the management of pyridaben resistance in the field (Young *et al.*, 2006).

Herron *et al.* (1993) confirmed resistance in *T. urticae* to an IGR (clofentezine). The resistance in population from Queensland glass house roses was extremely high

(>2500X), which also conferred high level of cross-resistance to unrelated compound hexythiazox.

The resistance ratios of *T. urticae* populations ranged from 19.8 to 28.8 and 16.8 to 39.8 for fenazaquin and tebufenpyrad, respectively when compared to the more susceptible reference populations from apple orchards in the Southern France. The resistance was high for tebufenpyrad than for fenazaquin (Romain *et al.*, 2003).

Studies with *T. urticae* populations in Turkey revealed the relative toxicity of abamectin to dicofol resistant and susceptible strains as 0.12 and 0.60 ppm, respectively, when all the adult females of these strains were killed. The lower concentrations of 0.06 and 0.012 ppm killed more than 77 per cent of adult females of these strains (Francisca Campos *et al.*, 1995).

The level of susceptibility in adult females of European red mite, *P. ulmi* populations from apple orchards in Bursa region of Turkey to acaricides, dicofol, bromopropylate, fenpyroximate and amitraz (acaricide-insecticide) was determined by a Petri leaf disk - Potter's spray tower method. When compared with the susceptible population, resistance ratios, as indicated by LC_{50} values, ranged from 2.2 to 11.9, 0.8 to 3.6, 1.0 to 22.5 and 0.9 to 7.9, while LC_{90} values varied from 1.6 to 9.8, 1.0 to 5.4, 1.0 to 47.4 and 1.4 to 36.6, for amitraz, dicofol, bromopropylate and fenpyroximate, respectively. Susceptibility was low for fenpyroximate and bromopropylate than for the other two compounds, amitraz and dicofol. This suggested that the susceptibility of *P. ulmi* to these compounds varied widely with location in the Turkey region (Bahattin *et al.*, 2007).

2. 4. Resistance management in mites

Young *et al.* (2006) suggested the following for management of pesticide resistant mite population:

a) Mite damage is a function of time in crops like grapes, early populations of mites before bud differentiation could be more damaging than the same number of mites occurring later, during the mid season. High populations of mites at mid or late season resulted in egg deposition in the calyx ends of fruit, which could not be removed. Keeping mite populations below the optimum numbers for reproduction is an important factor in mite control. Measures that maintain low mite populations and prevent the damage are more effective than eradicative measures that might be ineffective and be late to prevent the damage.

b) Miticides with different modes of action should be rotated within a season or from season to season to delay the development of resistance. Once resistance to a miticide has developed through selection pressure and the miticide is no longer used, the mite population will regress from homozygous resistance to heterozygous resistance. Therefore, a miticide to which resistance was developed some years ago can often be effective again, if employed only once in a season. It generally requires a few generations for the mites to regain the resistance. Such miticides could be effectively used in rotation with miticides having different mode of action.

c) Use pre-blossom applications of superior oil or organic miticides and summer applications of miticides as needed. If possible, use miticides that are selective against mites. To protect predators, avoid the use of pesticides such as carbamates, pyrethroids and other classes of compounds that are known to be detrimental to beneficial predators.

d) Solutions containing petroleum-based horticultural oils, vegetable oils or agricultural soaps can be applied on crops like grape vines. Adult mites including eggs are killed by suffocation when the oil or soap solution smoothed them. Extreme care should be taken with the use of these products to limit the chances for phytotoxicity.

e) Dicofol is an organochlorine miticide still available for use against mites and is relatively less persistent in the environment. Dicofol offers better mite control activities at warmer temperatures against spider mites, but it is recommended that this product should not be used more than once within a single growing season.

f) The efficacy of organotin compounds can be improved, if they are used during periods of warmer weather.

2.4.1. Control of spider mites on tomato and other crops using newer acaricidal molecules

In a laboratory assay by Aji (2005) milbemectin was found more ovicidal on *T. urticae* (LC_{50} value of 3.77 ppm) followed by fenpyroximate (24.79 ppm), abamectin (38.06 ppm) and fenazaquin (86.08 ppm) and in a field study, he reported that within 3 days, fenpyroximate (@ 30 g a.i./ha) treated plots which recorded the lowest number of mites (eggs and active stages) *i.e.* 10.1/leaflet was most effective resulting in 76.8% reduction over control. Fenazaquin causing 71.8% reduction was next in the order of efficacy. Ten days after application still fenpyroximate treatments (15-30 g a.i./ha) showed significant reduction in the mite population (65 - 79%). After Fourteen days, newer acaricides like bifenthrin, clofentezine and fenpyroximate were found relatively more effective.

When *T. urticae* and *T. cinnabarinus* infested tomato and cucumber crops in green houses were sprayed with range of acaricides, mortalities of mites over 90% were obtained in most of the cases. But diafenthiuron and abamectin were singled out as most effective (Szwejda, 1993). Under high infestation pressure, acaricides such as abamectin, diafenthiuron and fenpropathrin gave excellent control of *T. cinnabarinus* on green house tomato and cucumber in Poland. After 14 days more than 98% mortality of the mobile stages was observed (Szwejda, 1994). According to Undurraga and Dybas (1998), abamectin at 13.5–27 g. a. i./ha plus 0.25% mineral oil controlled *Tetranychus* spp. on tomatoes in USA, Mexico and Argentina and in South Africa, it was effective @ 10 - 22 g a. i./ha.

Judicious application of propargite (Omite 57EC) or fenpyroximate (Ortus 5EC) or dicofol (Mitigan 18.5 EC) or diafenthiuron (Pegasus 25 EC) and timely release of *P. persimilis* offered maximum protection of tomatoes from spider mites in green houses and open fields in Bulgaria (Atanasov *et al.*, 1995).

Legrand *et al.* (1999) carried out field trials in Belgium for the control *T. urticae* on sugarbeet using newer products, namely bifenthrin, fenazaquin, thiometon + fluvalinate, hexythiazox and a mixture of hexythiazox and pyridaben. Except for the formulation thiometon + fluvalinate, all other products provided good control of mites upto one month.

Aguiar *et al.* (1993) evaluated different doses of diafenthiuron against *T. urticae* on green house roses at 28^{0}C and 70% RH. Diafenthiuron was highly efficient at 30 and 40g a. i./100 litres of water. Mortalities obtained were comparable with those obtained with abamectin at 20 ml a. i./100 litres of water. Different concentrations of clofentezine and abamectin were tested against *T. urticae* on roses in green houses, clofentezine at 25g and abamectin at 3.6 g a. i. in 100 litres of water were effective against the mite (Aguiar *et al.*, 1995).

Acute lethality of fenazaquin against *T. urticae* adults infesting glass house rose was assessed by Sekulic *et al.* (1998). Adults were 10 times less susceptible than other developmental stages, but a glasshouse trial on cucumber and tomato showed that fenazaquin at 80 and 120 mg/litre had good efficacy seven days after application, the efficacy declined after 14 days. Onkarappa (1999) found that abamectin (4.5ppm) and dicofol (0.044%) were effective in suppressing the two spotted spider mite population on green house rose. Akashe (2002a) noticed the lowest LC_{50} value of 0.000041% for abamectin 1.9 EC followed by clofentezine 50 SC (0.00095%) indicating higher toxicity compared to diafenthiuron and dicofol. In another study Akashe (2002b) compared the efficiency of different newer acaricides during summer season. The highest mortalities of 87.43% and 86.35% were recorded with abamectin (0.00045%) and clofentezine (0.006%), respectively. Dicofol (0.05%) caused a mortality of 82.63% and diafenthiuron (0.075%) caused 72.94% mortality.

Green and Dybas (1984) found that abamectin was effective against *T. urticae* on ornamentals when applied at the rate of 1.5 litres/ha. Similarly, Lasota and Dybas (1990) and Masis and Aguilar (1990) reported that abamectin @ 5-27 g a.i./ha was effective on phytophagous mites infesting strawberry, citrus, cotton, pear and vegetables.

When chemical control of the two spotted spider mite, *T. urticae* was carried out in Switzerland, acaricides like, clofentezine (Apollo), fenpyroximate (Kiron), fenazaquin (Magister) and abamectin (Vertimec) were found more effective on strawberry during summer months (Antonin *et al.*, 1997). Greater efficacy of clofentezine (Apollo), dicofol + tetradifon (KT22) and fenazaquin (Magister) against *T. urticae* on strawberry crops in green houses in Italy was observed by Nicotina and Ernesto (1998). Mixtures of fenazaquin with an ovicide (clofentezine of unstated concentration) gave good control. Fenazaquin at 50 g a.i./100 litres alone was insufficient to contain the infestation, although fenazaquin used alone at 75g a.i./100 litres showed good efficacy, dicofol + tetradifon was less effective. Allen *et al.* (1997) reported that *T. urticae* populations were significantly suppressed by abamectin and clofentezine on apple and pear crops.

Curkovic *et al.* (1999) evaluated fenazaquin and fenpyroximate against *P. ulmi* on apple and pear in comparison with pyridaben. Fenazaquin and fenpyroximate showed faster control of mobile individuals of *P. ulmi* under field conditions in Chile controlling 90% of the population in 3-9 days after application. Efficacy was directly proportional to fenazaquin concentration. Control with fenazaquin (>0.005% a.i.) and fenpyroximate (>0.025% a.i.) was statistically on par. Control of eggs was more than 77% with 0.005-0.010% fenazaquin, which was similar to the control by fenpyroximate at 0.025% a.i. Fenazaquin sprayed at 0.02% a.i. resulted in 97% control of eggs in both the fruit orchards and was superior to fenpyroximate.

El-Banhawy and Anderson (1985) conducted field experiments in cotton for the control of *T. urticae* and found that residual toxicity of avermectin B1 for ten days and the toxicity increased with the increase in temperature. Abamectin @ 10.8 g a.i./ha was found to be effective on *T. urticae* infesting cotton (Ramalho *et al.*, 1986 ; Clark *et al.*, 1995).

Vostrel (1996) investigated on the control of *T. urticae* on *Humulus lupulus* using Ortus (5% Fenpyroximate) and Magus 200 SC (20% fenazaquin). Fenazaquin gave complete mortality at 0.12% concentration and more than 95 per cent at 0.06% concentration. Fenpyroximate showed 84.5 and 100 per cent mortality at 0.1 and 0.05% concentrations, respectively.

An experiment with 11 insecticides with known or expected acaricidal activity was carried out against *T. urticae* on *Hedera helix*. The plants were thoroughly treated once using a knapsack sprayer and mortality was assessed after one week. Bifenthrin, dicofol and abamectin treatments gave proper control of *T. urticae* ranging from 85.7 to 98.5%. Abamectin at 0.5 ml formulated compound per litre of water resulted in 96 to 98% mortality of motile stages. Dicofol and bifenthrin could give a similar result, providing an adjustment of the dose or a second treatment (Heungens and Tirry, 2001).

Aucejo *et al.* (2003) conducted field experiment on the efficacy of ten acaricides against *T. urticae*. Of which Magister (fenazaquin), Bermectin and Crater (avermectin) were found to be very effective, Kendo (fenpyroximate) was not as effective as other acaricides.

Choi *et al.* (1997) attempted the control of *T. viennenis* on cherry, peach and apple in Korean Republic using different acaricides. Azocyclotin, pyridaben, propargite, tebufenpyrad and fenpyroximate were highly effective against females, while hexythiazox and clofentezine were least effective and all these acaricides were found highly effective against eggs.

Use of ovicides, antimetabolites *etc.*

Clofentezine and hexythiazox are selective ovicidal products and spider mite eggs exposed to these compounds failed to hatch. Both these chemicals are selective and aid in the conservation of beneficial arthropods. These products are typically used on crops relatively early in the production season before the mite populations reach the epidemic conditions. The use of newer molecules like abamectin, fenpropathrin, bifenthrin, pyridaben and chlorfenapyr with extended effectiveness against spider mites has been suggested (Young *et al.*, 2006).

Use of pesticide tolerant natural enemies

Markwick (1986) reported that the two species of phytoseiid mites, *Typhlodromus pyri* and *Phytoseilus persimilis* developed resistance to cypermethrin and fenvelarate respectively, after six selections. Cross-resistance of *T. pyri* to deltamethrin was observed, but *P. persimilis* did not show any significant difference in the survival rate even after repeated selections. Yan *et al.* (1996) noticed fenvalerate resistance in a strain of *Amblyseius pseudolongispinosus*, which showed LC_{50} value 65 times higher than that of the wild strain after 18 selection cycles, but was unstable in the absence of selection pressure.

Hoy and Ouyang (1989) detected resistance to abamectin and fenbutatin oxide in phytoseiid predators. The predatory mite, *Metaseiulus occidentalis*, after selection over 20 generations showed 3.8-folds increase in LC_{50} of abamectin and the increased rate of survival was attributed to increased fecundity of adult females.

Horn *et al.* (1994) showed development of fenbutatin oxide resistance in the laboratory strain of *P. persimilis* after 108 selections, the selected *P. persimilis* displayed 50-folds increase in LC_{50} as compared with the parent strain. The concentration of fenbutatin oxide used to maintain selection exceeded the recommended rate of application.

Species of phytoseiid mite predator *Neoseiilus longispinosus* has been found promising against spider mite infestation in controlled conditions (Mallik *et al.*, 2003). Sugeetha (2004) showed that phytoseiid predator *Amblyseius longispinosus* attained 24 folds resistance to dicofol after 40 selections. But stability of resistance was not observed, within 5 generations tolerance declined by 15%. Dicofol resistant predator population showed multiple resistances to dimethoate, profenophos, monocrotophos and endosulfan and zero resistance to abamectin, milbemectin and triazophos.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The present investigations on *Tetranychus urticae* Koch infesting tomato included establishing base-line values for its susceptibility to wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite, monitoring the level of resistance to these compounds in *T. urticae* populations from Bangalore and Kolar districts and field evaluation of newer acaricidal molecules. All the laboratory experiments were carried out in the Acarology section of the Department of Agricultural Entomology, University of Agricultural Sciences, G.K.V.K, Bangalore and the field investigations were carried out in farmer's fields in Vadagur and Chintamani in Kolar district and in Rajanukunte and Hoskote in Bangalore district during 2006-08. The details of the material used and methodology adopted during the course of these investigations are presented hereunder.

3.1.Establishing base line values for susceptibility of *Tetranychus urticae* Koch to selected acaricides

3.1.1. Development of susceptible culture in the laboratory

Two spotted spider mite, *T. urticae* was collected from naturally infested tomato crop in the field at GKVK Campus and reared for two generations on tomato leaves kept on wet cotton wad in Petri plates. Subsequently the mite culture was maintained on mulberry leaves kept on moist cotton wad in large plastic or aluminum trays. This mite culture was maintained in the laboratory for thirty eight generations as a susceptible laboratory population without exposing it to any acaricide and used for determining base-line values for susceptibility to acaricides namely, wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite.

The biology of the mite was studied to record the duration of different developmental stages and also the duration from egg to egg. This was considered as the time taken for completion of one generation of the mite.

3.1.2 Determination of base-line values for susceptibility of *T. urticae* to acaricides

Base-line values are the median lethal concentration (LC_{50}) values determined for the susceptible laboratory culture of *T. urticae* during different generations. LC_{50} values were determined following Leaf Dip Bioassay method. Before fixing the testing concentrations for bioassay, preliminary studies were carried out with two wide concentrations and for each bioassay 6-8 testing concentrations that would give mortalities ranging from 20-90% were used to prepare concentration-mortality regression lines. Stock solution of the highest concentration was prepared initially and then serially diluted to get the required lower concentrations. Fresh tomato leaflets were dipped in desired concentration of acaricides for 5 - 10 seconds and air dried under a ceiling fan. Such treated leaflets were kept on wet cotton wads in a Petri plate and on these leaflets thirty active adult females were released as one replication, and three such replications were maintained along with a water treated control.

Observations on the mite mortality were recorded up to 4 days at 24 h interval. During each observation the mites which were found drowned or entangled to cotton fibers were placed back carefully on the corresponding leaflet using a fine camel hair brush and the observations were continued. Mites which were live, but were not able to move when gently prodded with a soft hair brush were considered as moribund or dead.

The mortality data recorded were corrected using Abbott's formula (1925) depending on the mortality observed in the control. The corrected mortalities were subjected to Probit Analysis (Finney, 1971) for determining concentration - mortality responses and the Median Lethal Concentration (LC_{50}) values. LC_{50} values were determined for the susceptible laboratory culture during 5th, 15th, 25th and 38th generations for different acaricidal chemicals. LC_{50} value in the 38th generation was considered as the base-line value of the laboratory susceptible population and also this population was considered as the reference strain for calculating the extent of resistance as Resistance Ratio. LC_{50} values determined for different generations of the susceptible laboratory culture were used to understand the progressive susceptibility in the laboratory population over generations. The commercial formulations of acaricides were used in all the laboratory assays and the details of acaricides used in the present investigations on acaricide resistance in two spotted spider mite, *T. urticae* infesting tomato were:

Table 1. Details of acaricides used in resistance studies

Sl No.	Chemicals	Trade name	Manufacturer
1	Wettable sulphur	Sultaf 80WP	M/s Rallis India Ltd., Mumbai
2	Dicofol	Colonel-S 18.5 EC	M/s Indofil Chemicals Co. Mumbai
3	Abamectin	Vertimec 1.9 EC	M/s Syngenta company Ltd., Mumbai ; Willwood Agro-Chem. Pvt.Ltd., Chennai
4	Diafenthiuron	Pegasus 50 WP	M/s Syngenta Company Ltd., Mumbai
5	Fenazaquin	Magister 10EC	M/s E.I. DuPont India Pvt. Ltd., Gurgaon, Haryana
6	Propargite	Omite 57 E.C	M/s Northern Minerals Ltd., Gurgaon, Haryana

3.2.1. Monitoring the level of resistance in different populations of *T. urticae*

To assess the level of resistance, *T. urticae* populations on tomato were sampled from two locations each from two districts, Bangalore (Rajanukunte and Hoskote) and Kolar (Chintamani and Vadagur). Mite populations on tomato were collected from farmer's field at two different intervals (monthly or bimonthly) during the cropping season between July 2007 and January 2008. When mite populations collected were sufficient in number they were directly used for bioassay studies with different acaricides namely, wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite. When the mite population was not sufficient, population from F_1 progeny was used for the bioassay studies. Leaf dip bioassay method with at least 6 concentrations for each of the acaricides were used to determine the LC_{50} values and to construct concentration-mortality lines (Log concentration - Probit response lines) following Probit Analysis (Finney, 1971).

The LC_{50} values determined for field populations at different intervals were compared with the LC_{50} value of the susceptible laboratory culture in the 38th generation and used for detecting and quantifying the level of resistance as Resistance Ratio.

$$\text{Resistance Ratio} = \frac{LC_{50}\text{ of chemical to the field population at a particular interval}}{LC_{50}\text{ of chemical to the susceptible laboratory population in the 38}^{th}\text{ generation (reference strain)}}$$

3.2.2. Evaluation of newer acaricides against two spotted spider mite *T. urticae* infesting tomato

In an effort to exercise satisfactory control of pesticide resistant spider mite population, the mite infested tomato crop in a farmer's field in Vadagur village of Kolar district was selected to evaluate a few newer acaricidal molecules in comparison with the conventional acaricide, dicofol. The details of acaricides used in the field experiment were:

Table 2. Acaricides used in tomato field experiment at Vadagur in Kolar

Acaricides	Dose / Conc.	Trade name	Manufacturer
Abamectin	6 g a.i./ha	Vertimec 1.9 EC	Syngenta India Ltd., Mumbai ; Willwood Agro-Chem. Pvt.Ltd., Chennai
Chlorfenapyr	75 g a.i./ha	Intrepid 10 SC	BASF India Ltd., Mumbai
Diafenthiuron	450 g a.i./ha	Pegasus 50 WP	Syngenta India Ltd., Mumbai
Fenazaquin	125 g a.i./ha	Magister 10 EC	EI DuPont India Pvt. Ltd., Gurgaon (Haryana)
Fenpyroximate	30 g a.i./ha	Sedna 5 SC	Rallis India Ltd., Mumbai
Milbemectin	4 g a.i./ha	Milbeknock 1EC	Nagarjuna Agrichem Ltd., Hyderabad
Propargite	570 g a.i./ha	Omite 57 EC	Northern Minerals Ltd., Gurgaon (Haryana)
Mineral oil	10 ml/lit.	MAK All Season HMO	Bharat Petroleum Corp. Ltd., Mumbai.
Fish oil rosin soap	5g/lit.	FOSCO	Crops Care (India) Products, Mangalore
Dicofol	2.5ml/lit.	Colonel-S 18.5 EC	Indofil Chemicals Co., Mumbai
Wettable sulphur	2.5g/lit	Sultaf 80 WP	Rallis India Ltd., Mumbai

The experiment was laid out in Randomized Complete Block Design with 12 treatments and 3 replications during summer 2008 (February - May). The plot size was 5m x 5m with a row spacing of 1m and plant to plant spacing of 30 cms. When the tomato crop (variety Abhinava) was 100-110 days old with high mite infestation different acaricides were sprayed uniformly using a high volume knapsack sprayer at the rate of 300 litres of spray fluid per acre.

For recording observations, from each plot five plants from the inner rows were selected at random and from each plant six leaflets two each from top, middle and bottom canopies were sampled and brought to the laboratory in polyethylene covers. The number of eggs and active stages (larvae, nymphs and adults) of spider mites on both the surfaces of leaflets was recorded using a stereobinocular microscope and the mite population was computed as the mean number (eggs or active stages or eggs and active stages) per leaflet. The pretreatment counts were made one day before spray and post treatment observations were recorded on the 3^{rd}, 7^{th}, 10^{th} and 14^{th} day after each application.

The population data recorded were subjected to statistical analysis after $\sqrt{x}+0.5$ transformations and analysed statistically following ANOVA technique for Randomised Complete Block Design and the results were interpreted at 5% level of significance. The effectiveness of different acaricides was compared both in terms of mite population as well as per cent reduction in mite population observed over untreated control using the following Henderson and Tilton's formula (1955).

$$\text{Per cent reduction over control} = 1 - \left[(Ta/Tb) \times (Cb/Ca) \right] \times 100$$

Where, Ta = population in treated plot after spray/treatment
Tb = population in treated plot before spray/treatment
Ca = population in control plot after spray/treatment
Cb = population in control plot before spray/treatment

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the present investigations carried out during 2006-08 on the establishment of base-line values for susceptibility of laboratory population of *Tetranychus urticae* to selected acaricides, assessment of resistance in different populations of *T. urticae* to wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin, propargite and evaluation of newer molecules against this mite in a farmer's field in Kolar district are presented in this chapter.

4.1. Base-line values for susceptibility of laboratory population of *T. urticae* to selected acaricides

Susceptibility of successive generations of *T. urticae* to different pesticides are presented in Table 1 and depicted in Fig. 1 - 6.

The LC_{50} values of wettable sulphur for the 15^{th} and 38^{th} generation of *T. urticae* laboratory population were 0.02110% and 0.01135%a.i, respectively. The susceptibility of the laboratory population to wettable sulphur increased over generations as the LC_{50} values decreased from 0.02110% to 0.01135% a.i. (Table 1) (Fig.1).

The LC_{50} values of dicofol for the 5^{th}, 25^{th} and 38^{th} generations were 0.01832, 0.00005 and 0.00001% a.i, respectively. The susceptibility of laboratory population to dicofol was found to increase over generations as the LC_{50} values decreased from 0.01832% to 0.00001% a.i. (Fig. 2)

The LC_{50} values for abamectin in the laboratory populations of *T. urticae* in 25th and 38th generations were 0.00005% and 0.00001% a.i., respectively. As observed with other acaricides susceptibility increased over generations (Fig. 3).

The susceptibility of *T. urticae* to diafenthiuron in its 15^{th}, 25^{th} and 38^{th} generations are depicted in Fig. 4 and the corresponding LC_{50} values of diafenthiuron were 0.00027%, 0.00014% and 0.00001% a.i, respectively, which

Table 1. Development of susceptible population of *Tetranychus urticae* in the laboratory

Generation in the laboratory	LC_{50} (% a.i.)					
	Wettable sulphur	Dicofol	Abamectin	Diafenthiuron	Fenazaquin	Propargite
5th	ND	0.01832	ND	ND	ND	ND
15th	0.02110	ND	ND	0.00027	0.00051	0.00030
25th	ND	0.00005	0.00005	0.00014	0.00005	0.00024
38th	0.01135	0.00001	0.00001	0.00001	0.00001	0.00003

** ND: Not Determined*

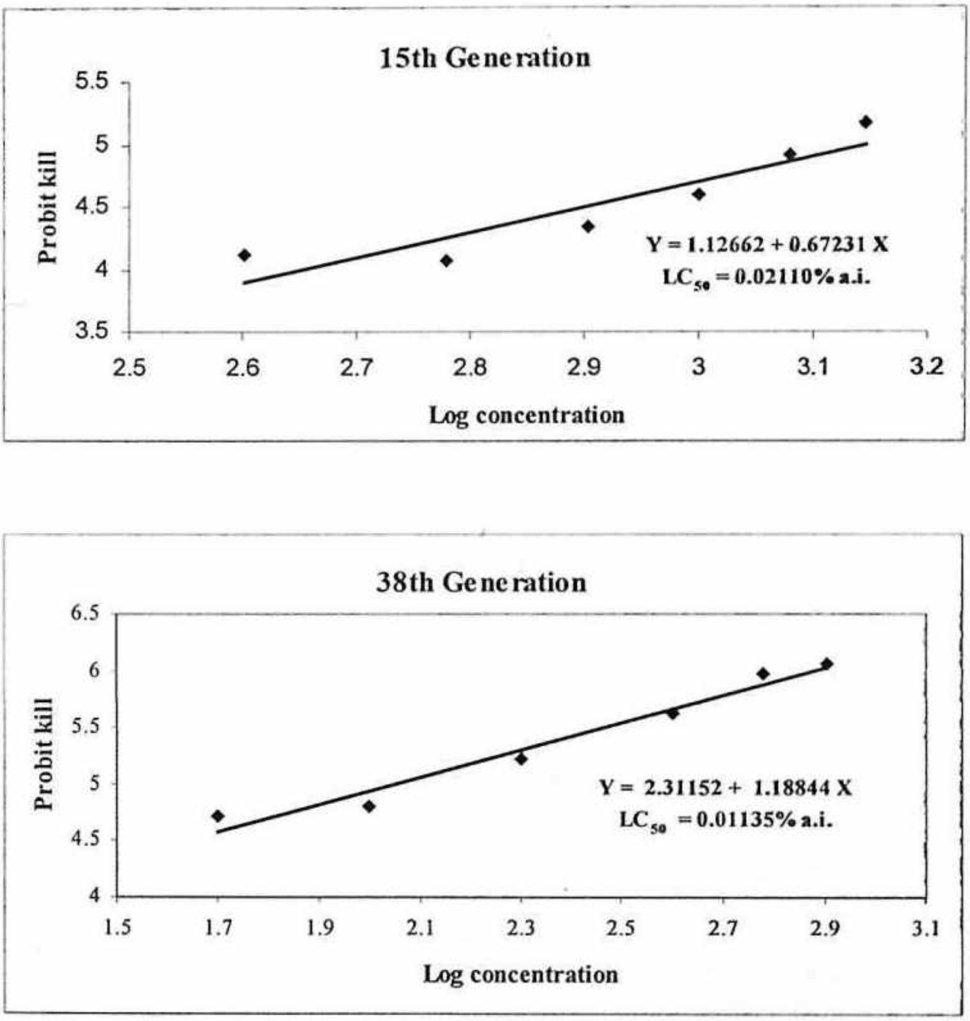


Fig. 1. Dosage-mortality response of laboratory population of *Tetranychus urticae* to wettable sulphur over generations

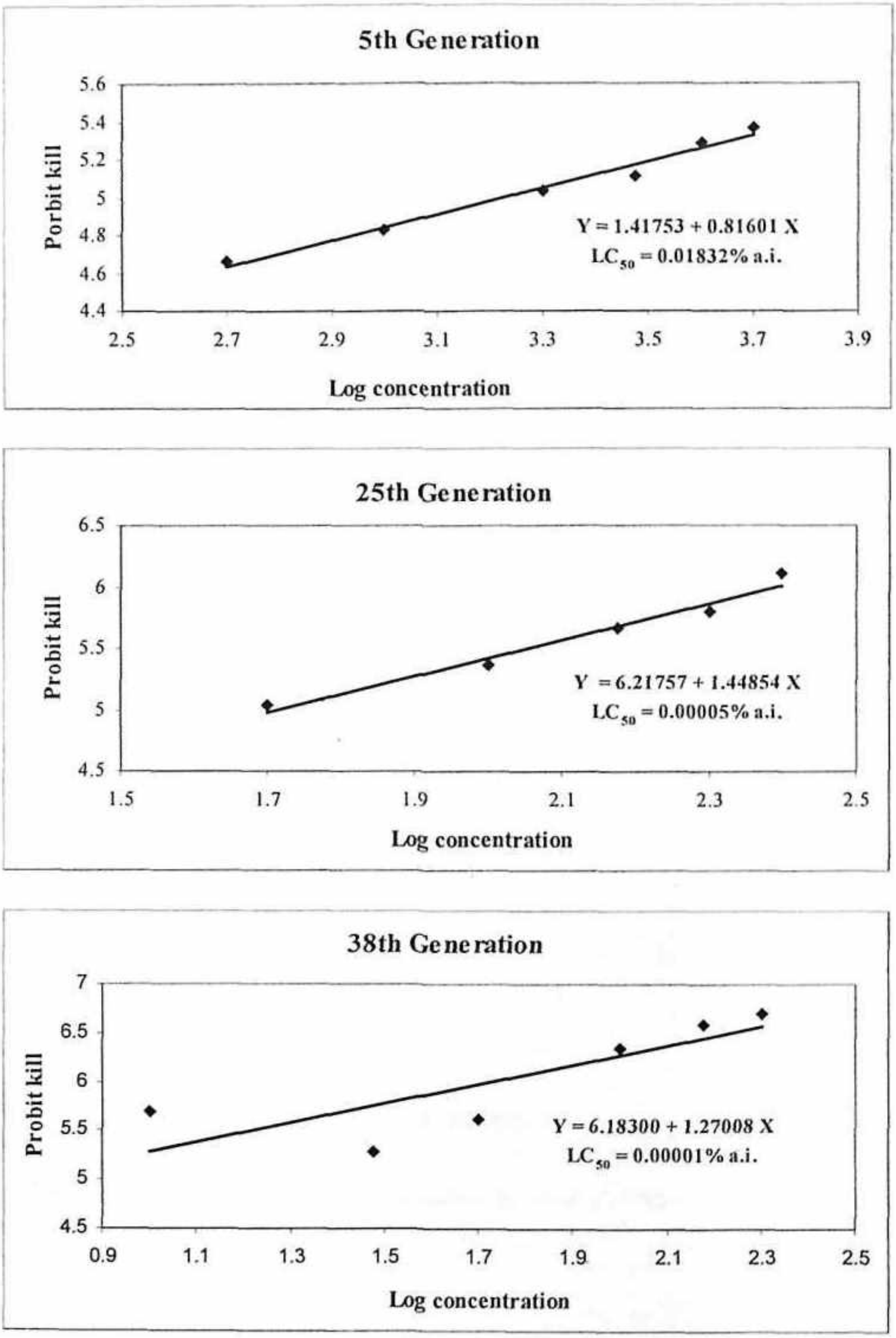


Fig. 2. Dosage-mortality response of laboratory population of *Tetranychus urticae* to dicofol over generations

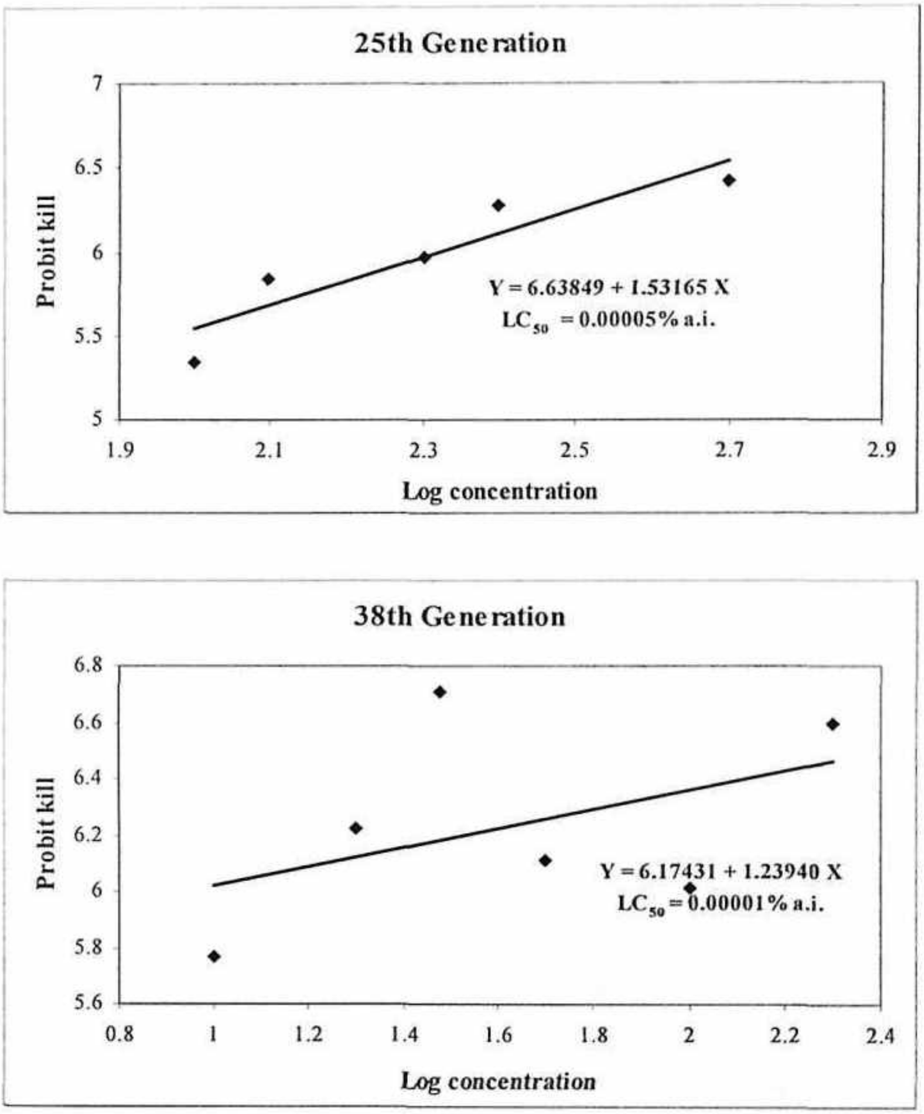


Fig. 3. Dosage-mortality response of laboratory population of *Tetranychus urticae* to abamectin over generations

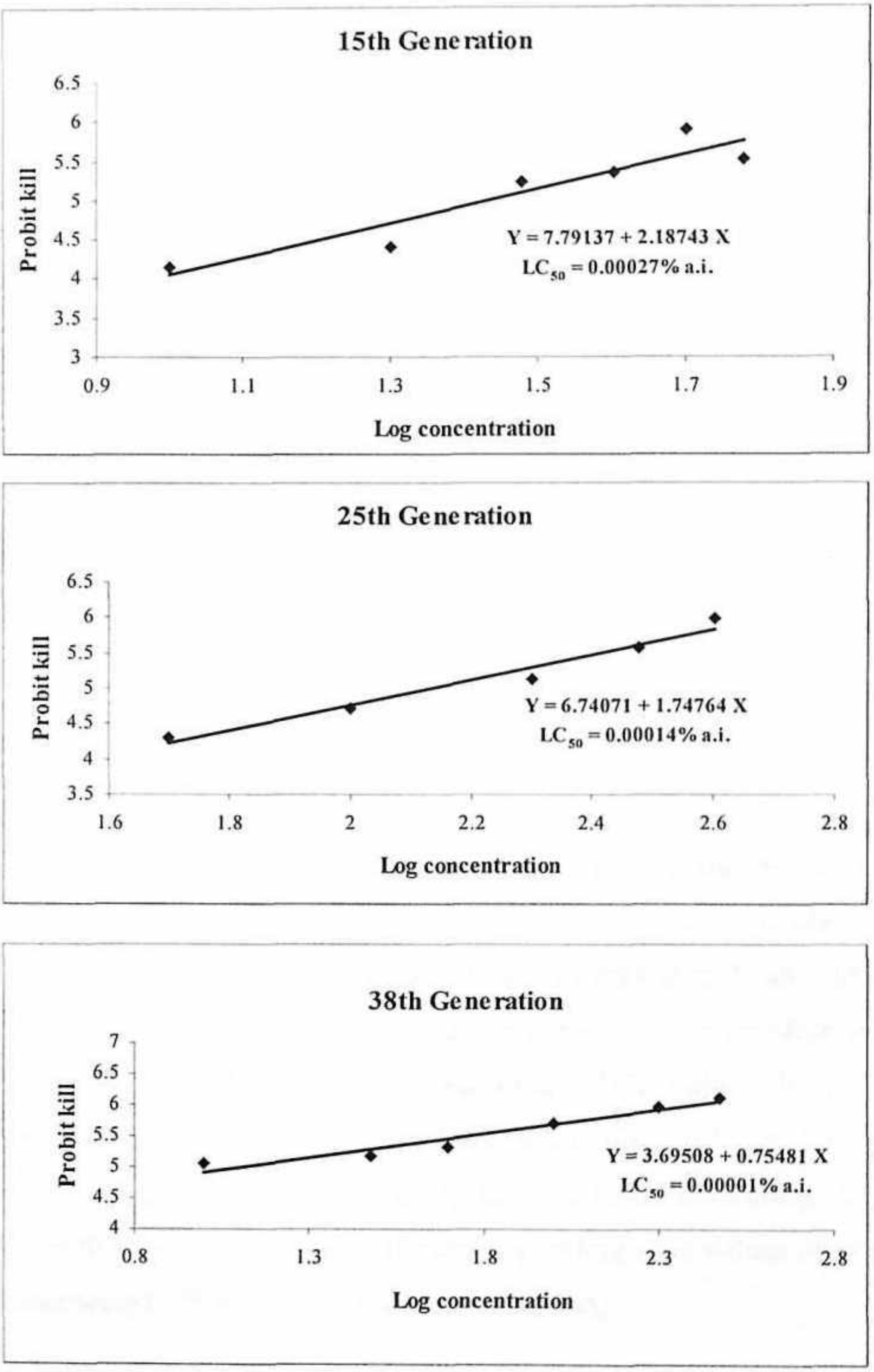


Fig. 4. Dosage-mortality response of laboratory population of *Tetranychus urticae* to diafenthiuron over generations

indicated increase in the susceptibility of the laboratory population in the successive generations. The LC_{50} value which was 0.00027% a.i. in the 15^{th} generation was found decreased to 0.00001% a.i. by 38^{th} generation (Fig. 4).

Increased susceptibility of the laboratory population of *T. urticae* was evident with fenazaquin, which is indicated by reduced LC_{50} values from 15^{th} to 38^{th} generation (Fig. 5).

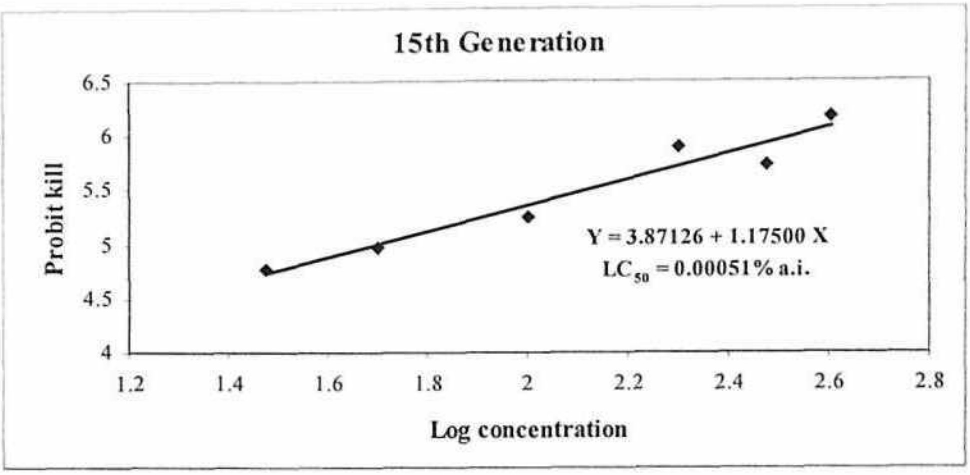
The LC_{50} values of propargite for the 15th, 25th and 38th generation of laboratory population of *T. urticae* were 0.00030%, 0.00024% and 0.00003% a.i, respectively. The susceptibility increased over successive generations as observed with other acaricides (Fig. 6).

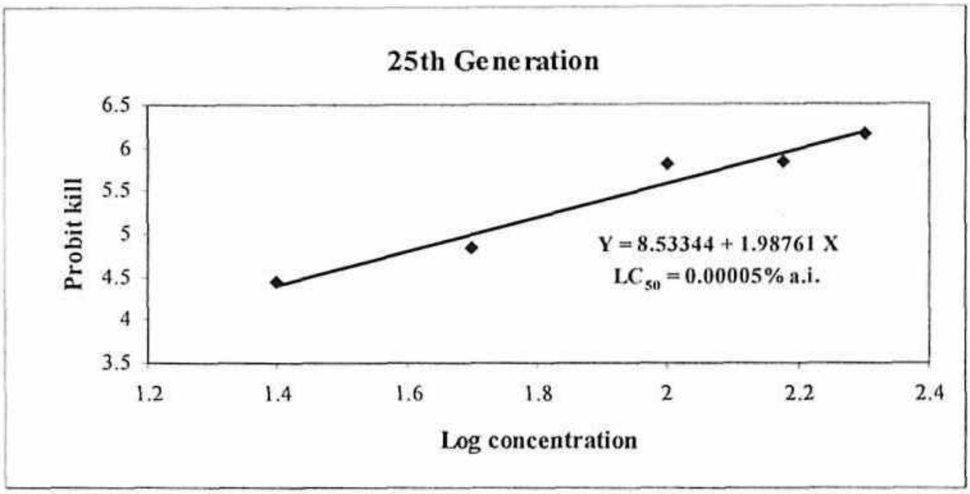
4.2. Acaricide resistance in Bangalore and Kolar populations of *T. urticae*

4.2.1. Resistance to wettable sulphur

Considering the LC_{50} values during the 38^{th} generation of the laboratory population resistance pattern observed in *T. urticae* populations from Bangalore and Kolar districts for wettable sulphur is given in Table 2 and depicted in Fig. 7. In Rajanukunte village of Bangalore district resistance which was observed to be 6.73 folds during third week of July was found increased to 17.46 folds by third week of August. Thus build up of resistance to wettable sulphur within the cropping season was evident. The corresponding LC_{50} values during July and August months were 0.07638% and 0.19820% a.i. (Fig. 7B). In Hoskote area, resistance to wettable sulphur was fairly low (26.10 folds) during August, but increased to 30.33 folds by October. The corresponding LC_{50} values during August and October were 0.2963% and 0.34422% a.i. (Fig. 7 A).

T. urticae populations from Chintamani in Kolar district were studied for their resistance to wettable sulphur (Fig. 7C). The level of resistance during the month of September 2007 which was 17.24 folds increased to 38.07 folds by the end





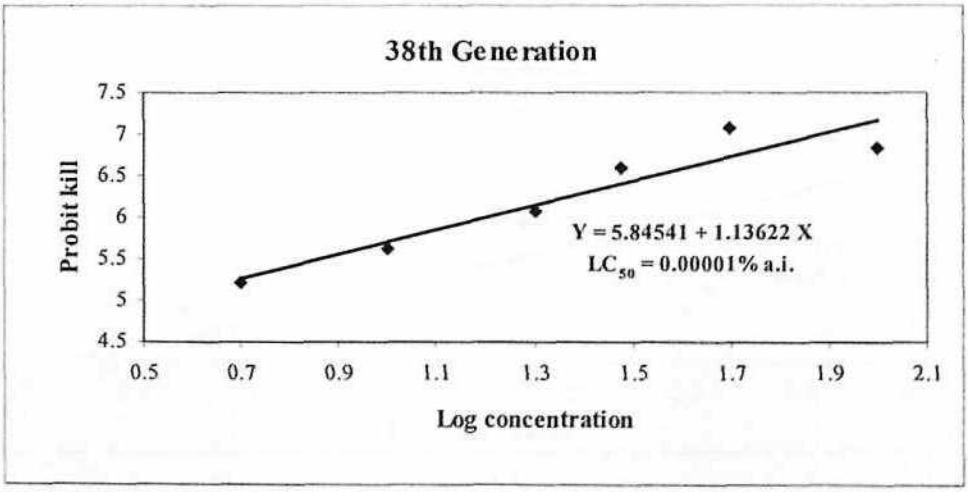


Fig. 5. Dosage-mortality response of laboratory population of *Tetranychus urticae* to fenazaquin over generations

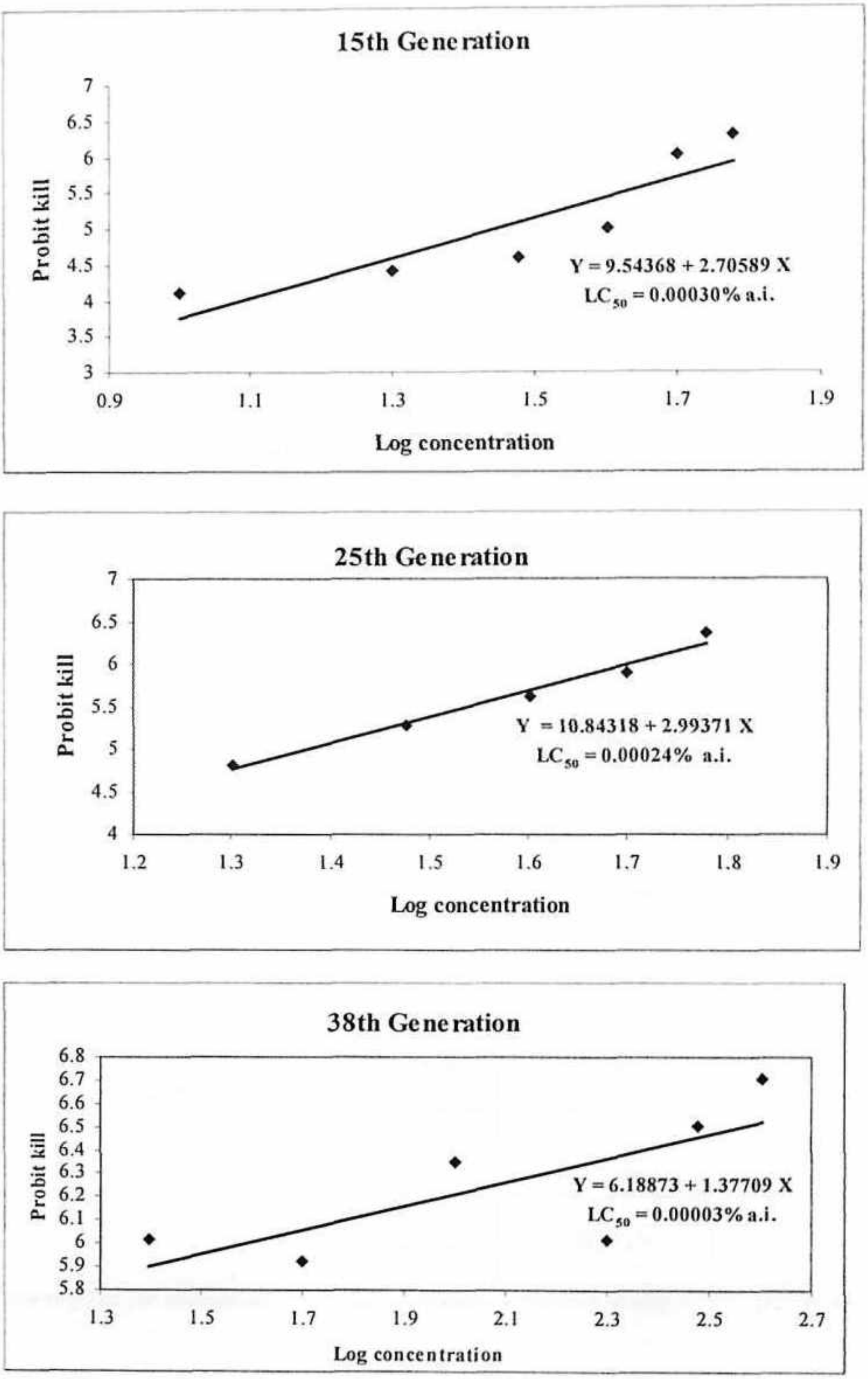


Fig. 6. Dosage-mortality response of laboratory population of *Tetranychus urticae* to propargite over generations

Table 2. Resistance to wettable sulphur in *Tetranychus urticae* populations from Bangalore and Kolar districts

Location		Date	LC_{50} (% a.i.)	Resistance Ratio (RR)
Bangalore	Hoskote	21-08-2007	0.34420	30.33
		09-10-2007	0.29629	26.10
	Rajanukunte	21-07-2007	0.07638	6.73
		19-08-2007	0.19820	17.46
Kolar	Chintamani	18-09-2007	0.19564	17.24
		23-10-2007	0.43209	38.07
	Vadagur	26-06-2007	0.03639	3.21
		08-09-2007	0.20565	18.12
		11-12-2007	0.22967	20.24
		02-02-2008	0.07715	6.80

****LC_{50} of wettable sulphur for susceptible T. urticae population (reference strain) was 0.01135% a.i.***

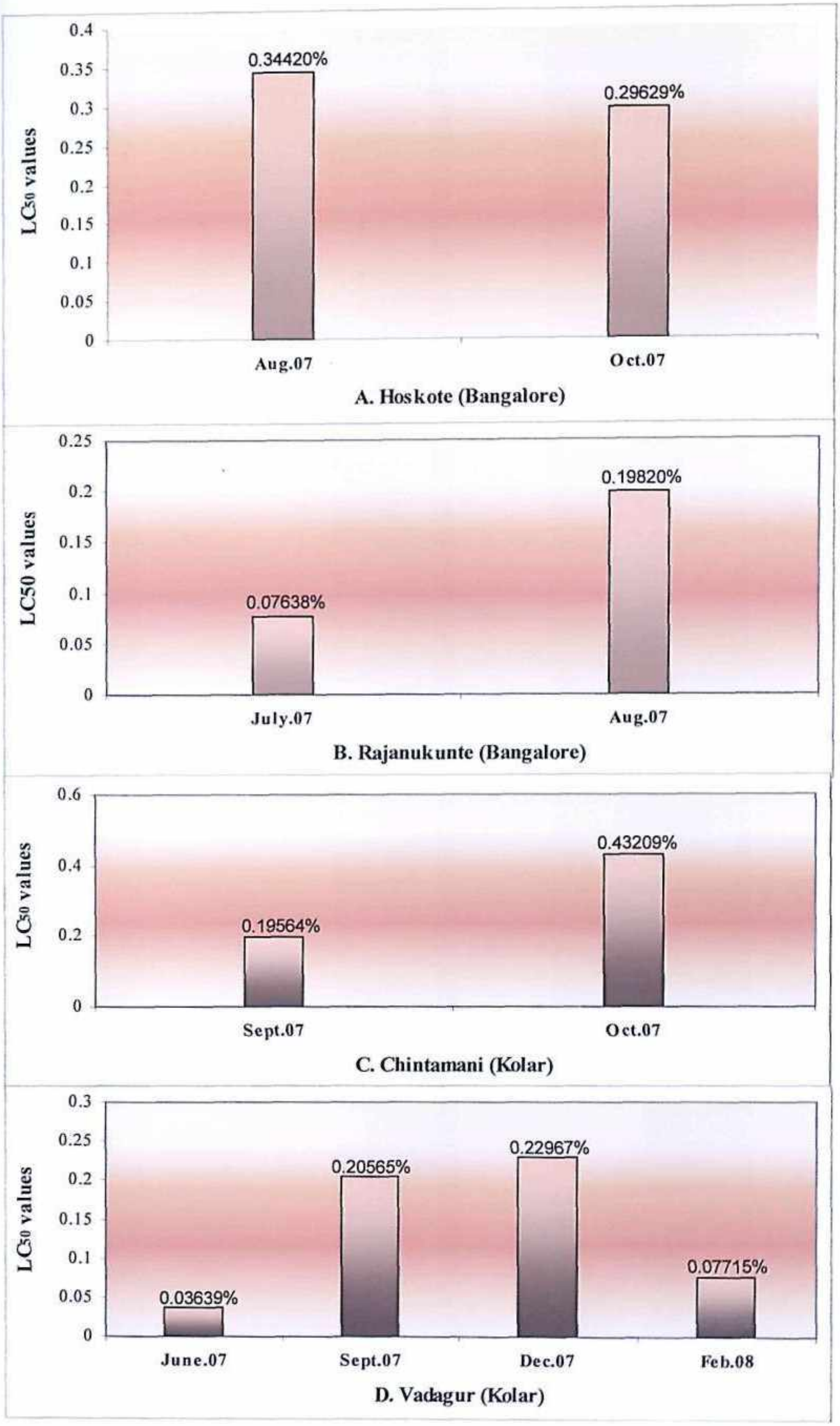


Fig. 7. Resistance to wettable sulphur in *Tetranychus urticae* populations from Bangalore and Kolar districts

of October within the cropping season. The LC_{50} values were 0.19564% a.i. during September and 0.43209% a.i. during October. Resistance level in *T. urticae* populations from Vadagur, another location in Kolar district was low (3.21 folds) in June but increased to 18.12 folds in September as the age of the crop advanced and similar trend was observed between December 2007 and February 2008. The level of resistance was similar in population from rabi crop (Fig. 7 D). LC_{50} values of wettable sulphur determined during June, September, December 2007 and February 2008 were 0.03639%, 0.20565%, 0.22967% and 0.07715% a.i, respectively.

4.2.2. Resistance to dicofol

Pattern of resistance to dicofol in *T. urticae* populations from Bangalore and Kolar districts are shown in Table 3 and depicted in Fig. 8. Considering the LC_{50} values of dicofol for the susceptible laboratory strain in the 38^{th} generation the level of resistance in Rajanukunte village of Bangalore district was observed to be 767 folds during last week of July which increased to 2923 folds after three weeks *i.e.*, during 3^{rd} week of August. The corresponding LC_{50} values during the period were 0.00767 % a.i. and 0.02923 % a.i, respectively. Similarly in Hoskote, another location in Bangalore district the level of resistance was 1146 folds during last week of August, it increased to 3690 folds by October. The corresponding LC_{50} values were 0.01146% a.i. and 0.03690% a.i. Thus the build up of resistance to dicofol within the cropping season was evident at both the locations in Bangalore district and the resistance level was highest in Hoskote (3690 folds) (Table 3 and Fig. 8 A &B).

In Kolar district *T. urticae* populations from Chintamani and Vadagur villages were studied for their tolerance to dicofol. The level of resistance during the early part of the season at these two locations was comparable (532 folds during 3^{rd} week of September 2007 at Chintamani and 500 folds during third week of June 2007 at Vadagur). However, resistance levels increased in Vadagur (3655 folds) in 4 months period compared to that observed at Chintamani (3266 folds)

Table 3. Resistance to dicofol in *Tetranychus urticae* populations from Bangalore and Kolar districts

Location		Date	LC_{50} (% a.i.)	Resistance Ratio (RR)
Bagalore	Hoskote	26-08-2007	0.01146	1146
		05-10-2007	0.03690	3690
	Rajanukunte	22-07-2007	0.00767	767
		15-08-2007	0.02923	2923
Kolar	Chintamani	18-09-2007	0.00532	532
		20-10-2007	0.03266	3266
	Vadagur	21-06-2007	0.00500	500
		07-09-2007	0.03655	3655
		08-12-2007	0.06491	6491
		31-01-2008	0.06046	6046

**LC_{50} of dicofol for susceptible T. urticae population (reference strain) was 0.00001% a.i.*

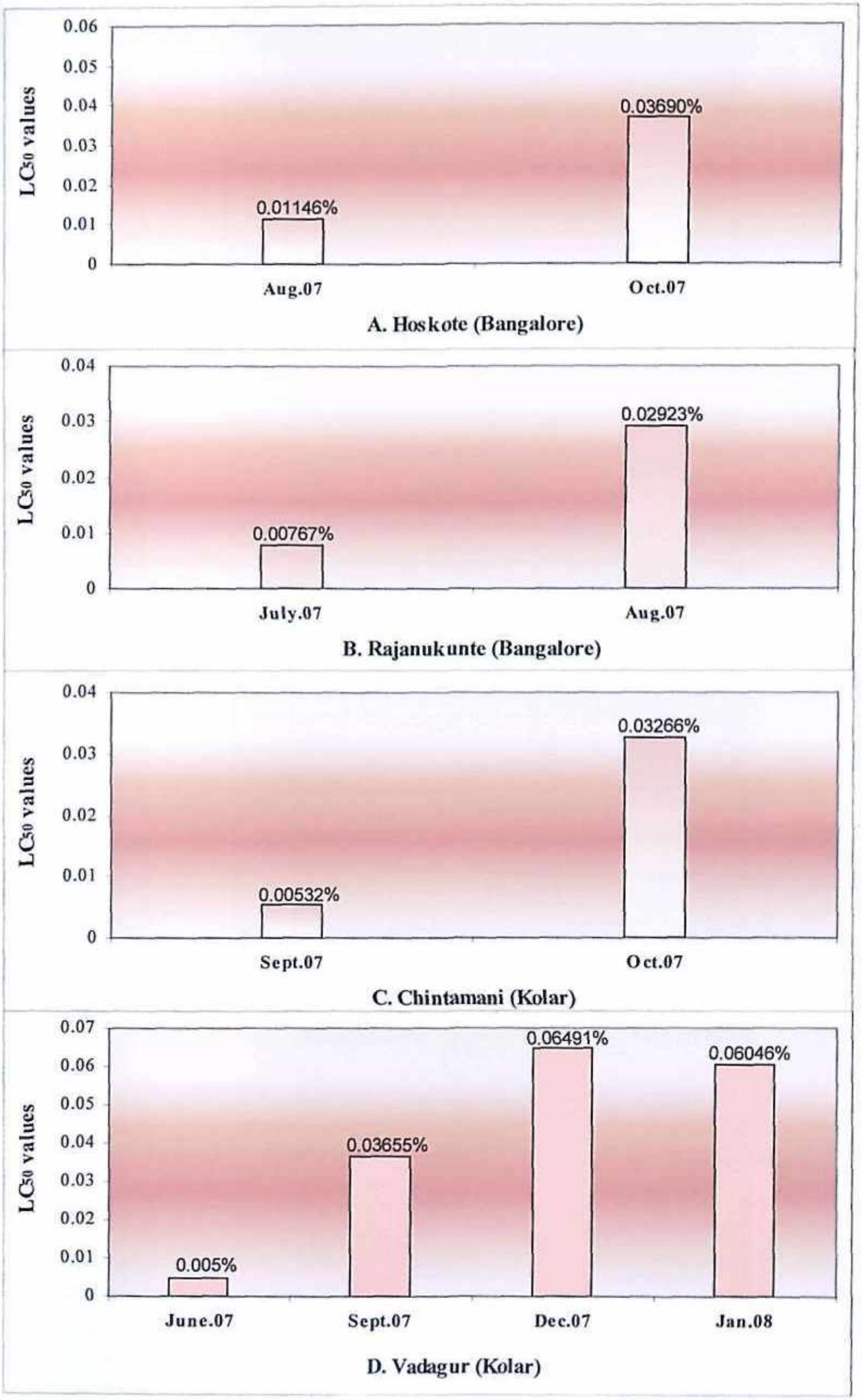


Fig. 8. Resistance to dicofol in *Tetranychus urticae* populations from Bangalore and Kolar districts

within one month. *T. urticae* population in Vadagur was highly resistant (6491 folds) in December 2007 compared to the resistance level of 6046 folds noticed in the following month of January 2008 (Table 3).

The LC_{50} values of dicofol determined for Vadagur populations during June, September and December 2007 and January 2008 were 0.0050%, 0.03655%, 0.06491% and 0.06046% a.i, respectively (Fig. 8D).

4.2.3. Resistance to abamectin

The pattern of resistance to abamectin was studied in *T. urticae* populations from Vadagur village only (Table 4). The level of resistance which was observed to be 4 folds during December 2007 increased to 8 folds in February 2008 with the corresponding LC_{50} values of 0.00004% and 0.00008% a.i. (Fig. 9). Thus, the tendency of resistance levels increasing within a growing season was noticed with abamectin also.

4.2.4. Resistance to diafenthiuron

Resistance to diafenthiuron in *T. urticae* populations from Bangalore and Kolar districts are shown in Table 5 and depicted in Fig. 10. The level of resistance in *T. urticae* population from Bangalore district was estimated to be 14 - 21 folds, while it was 18-26 folds in Kolar district. In the following month(s), the resistance was found enhanced significantly in both the districts (30 to 37 folds in Bangalore and 34 to 47 folds in Kolar) (Table 5).

Interestingly at Vadagur of Kolar district more gradual increase in resistance to diafenthiuron was apparent from June to December (2007). This indicated progressive diafenthiuron resistance in *T. urticae* populations from kharif season to rabi season (18 to 79 folds). Though the extent of resistance declined by the end of rabi crop, the resistance level was still fairly high *i.e.*, 67 folds (Table 5 and Fig. 10D). The LC_{50} values determined for Vadagur populations during June,

Table 4. Resistance to abamectin in *Tetranychus urticae* populations from Bangalore and Kolar districts

Location		Date	LC_{50} (% a.i.)	Resistance Ratio (RR)
Kolar	Vadagur	11-12-2007	0.00004	4
		02-02-2008	0.00008	8

LC_{50} *of abamectin for susceptible T. urticae population (reference strain) was 0.00001% a.i.

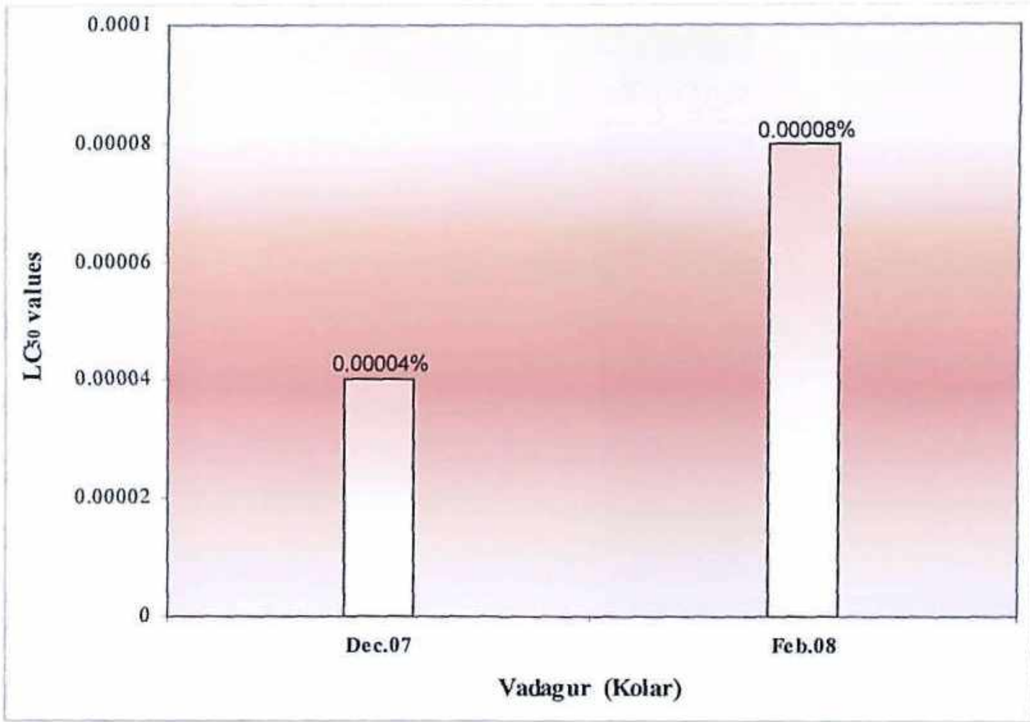


Fig. 9. Resistance to abamectin in *Tetranychus urticae* populations from Bangalore and Kolar districts

Table 5. Resistance to diafenthiuron in *Tetranychus urticae* populations from Bangalore and Kolar districts

Location		Date	LC_{50} (% a.i.)	Resistance Ratio (RR)
Bangalore	Hoskote	22-08-2007	0.00021	21
		10-10-2007	0.00030	30
	Rajanukunte	21-07-2007	0.00014	14
		20-08-2007	0.00037	37
Kolar	Chintamani	19-09-2007	0.00026	26
		23-10-2007	0.00047	47
	Vadagur	28-06-2007	0.00018	18
		08-09-2007	0.00034	34
		11-12-2007	0.00079	79
		02-02-2008	0.00067	67

******LC_{50}** ***of diafenthiuron for susceptible T. urticae population (reference strain) was 0.00001% a.i.***

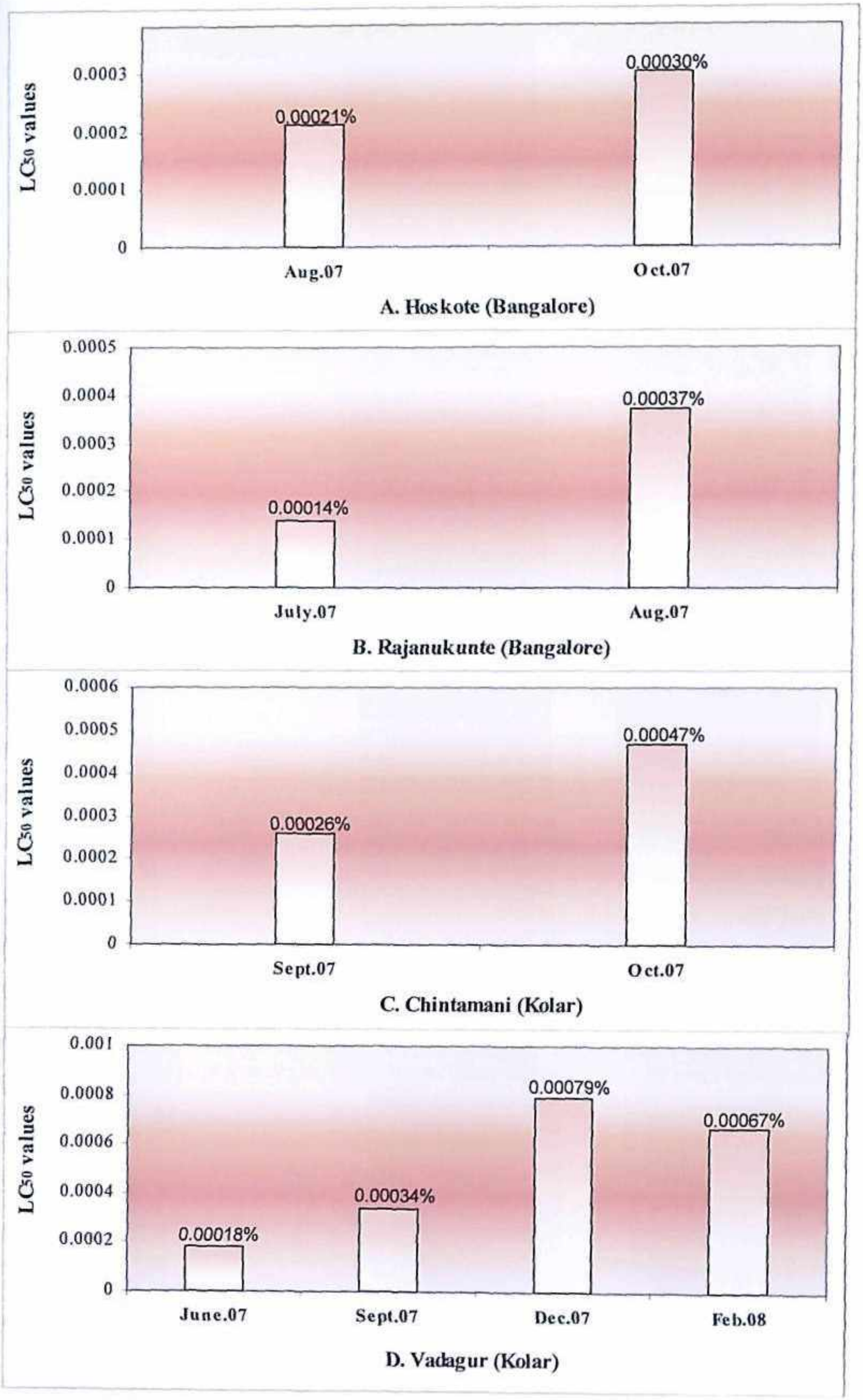


Fig. 10. Resistance to diafenthiuron in *Tetranychus urticae* populations from Bangalore and Kolar districts

September, December 2007 and February 2008 were 0.00018%, 0.00034%, 0.00079% and 0.00067% a.i, respectively.

4.2.5. Resistance to fenazaquin

In Bangalore district, *T. urticae* populations from Rajanukunte and Hoskote showed varied level of resistance to fenazaquin (Table 6 and Fig. 11). Populations from Hoskote were found more tolerant to fenazaquin than that of Rajanukunte (Fig. 11 A&B). The extent of resistance was high in Chintamani populations (25 folds) compared to populations from Vadagur (19 folds) during the kharif season. The corresponding LC_{50} values were 0.00009% to 0.00032% a.i, 0.00005% to 0.00016% a.i, 0.00013% to 0.00025% a.i and 0.00008% to 0.00019% a.i.

The expression of resistance to fenazaquin in Vadagur populations was more intense beyond September as the resistance ratio increased to 249 folds by December 2007 (Fig. 11D). But by February 2008 acaricide tolerance declined to 168 folds. The LC_{50} values of fenazaquin for resistance populations in December (2007) and February 2008 were 0.00249% and 0.00168% a.i, respectively.

4.2.6. Resistance to propargite

The progressive resistance observed with propargite in spider mite populations from Bangalore and Kolar districts are presented in Table 7 and illustrated in Fig. 12. At the beginning of kharif season, the extent of resistance to propargite at both the locations of Kolar district was similar (6 and 6.67 folds, respectively) (Table 7), while it ranged from 4-10 folds in Bangalore district. At all the locations the build up of resistance in the subsequent period was almost to the same level *i.e.*, 10.33 to 11.33 folds in Kolar and 10.33 to 11.67 folds in Bangalore with almost similar LC_{50} values (0.00031% to 0.00035% a.i.) (Fig. 12).

In Vadagur of Kolar district though the resistance ratio increased from 10.33 folds to 27.67 folds between September and December in 2007, successive populations showed a more stable resistance in the following month of January

Table 6. Resistance to fenazaquin in *Tetranychus urticae* populations from Bangalore and Kolar districts

Location		Date	LC_{50} (% a.i.)	Resistance Ratio (RR)
Bangalore	Hoskote	26-08-2007	0.00009	9
		06-10-2007	0.00032	32
	Rajanukunte	20-07-2007	0.00005	5
		16-08-2007	0.00016	16
Kolar	Chintamani	19-09-2007	0.00013	13
		21-10-2007	0.00025	25
	Vadagur	25-06-2007	0.00008	8
		09-09-2007	0.00019	19
		09-12-2007	0.00249	249
		01-02-2008	0.00168	168

****LC_{50}* of fenazaquin for susceptible T. urticae population (reference strain) was 0.00001% a.i.***

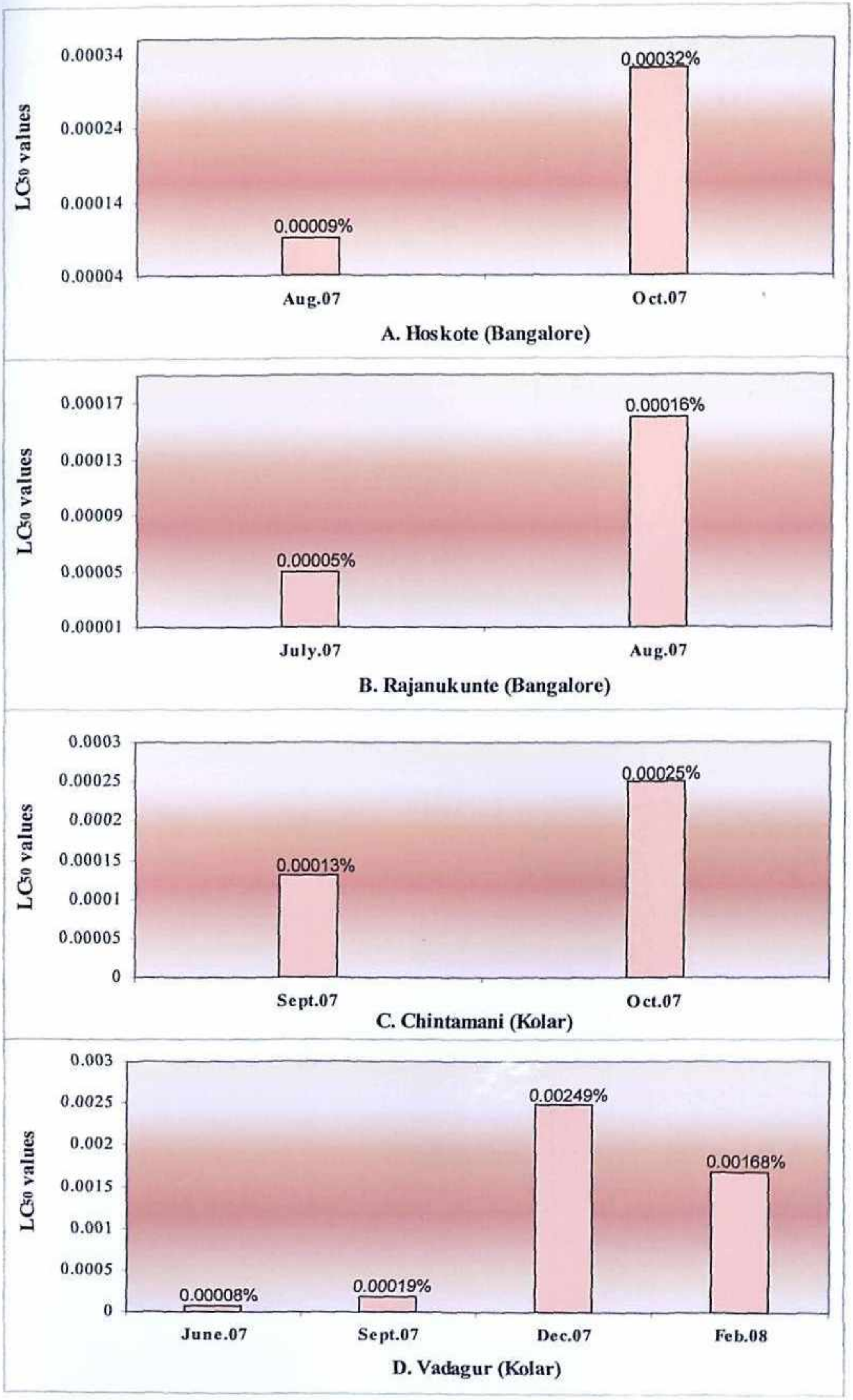


Fig. 11. Resistance to fenazaquin in *Tetranychus urticae* populations from Bangalore and Kolar districts

Table 7. Resistance to propargite in *Tetranychus urticae* populations from Bangalore and Kolar districts

Location		Date	LC_{50} (% a.i.)	Resistance Ratio (RR)
Bangalore	Hoskote	21-08-2007	0.00030	10
		09-10-2007	0.00035	11.67
	Rajanukunte	20-07-2007	0.00012	4
		17-08-2007	0.00031	10.33
Kolar	Chintamani	24-07-2007	0.00020	6.67
		21-09-2007	0.00034	11.33
	Vadagur	27-06-2007	0.00018	6
		07-09-2007	0.00031	10.33
		09-12-2007	0.00083	27.67
		01-02-2008	0.00080	26.67

**LC_{50} of propargite for susceptible T. urticae population (reference strain) was 0.00003% a.i.*

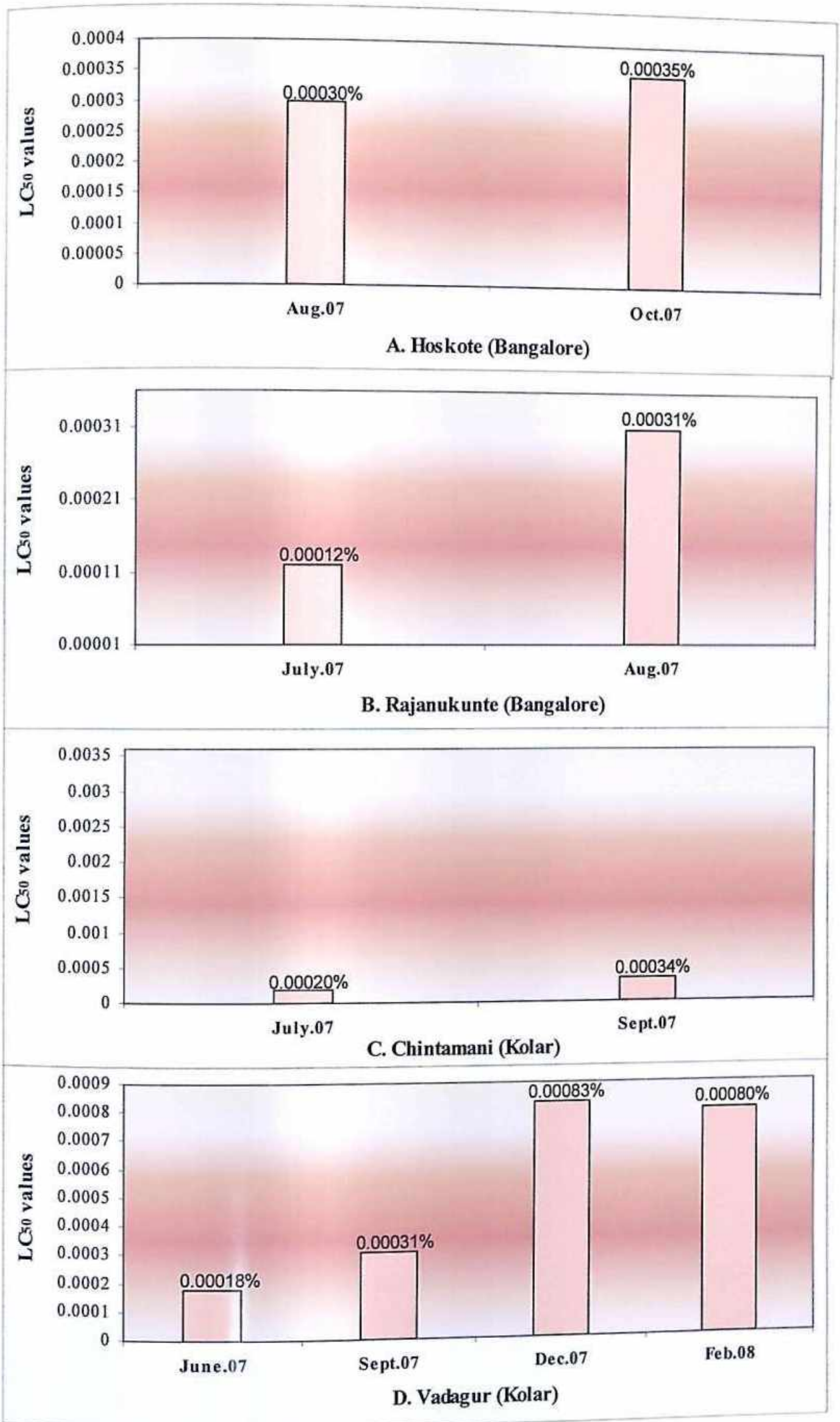


Fig. 12. Resistance to propargite in *Tetranychus urticae* populations from Bangalore and Kolar districts

2008 (26.67 folds). The corresponding LC_{50} values during December (2007) and January 2008 were 0.00083% and 0.00080% a.i.

4.3. Bioefficacy of newer acaricides against two spotted spider mite *T. urticae* infesting tomato

Tomato crop infested by spider mites in a farmer's field in Vadagur village of Kolar district was sprayed with various newer acaricidal molecules along with dicofol, wettable sulphur, mineral oil and fish oil rosin soap. Population of both eggs and active stages was recorded one day before application (pre-treatment) and 3, 7, 10 and 14 days after the application. Data on the efficacy of these compounds are presented in Table 8 to 13 and depicted in Fig (13 to 15).

4.3.1. Abundance of eggs

With regard to the abundance of eggs, acaricidal treatments differed significantly among themselves at all the intervals after the first application. Fenazaquin (125 g a.i/ha) treated plots recorded least number of eggs (17.92/leaflet) after 3 days and it was on par with the plots treated with chlorfenapyr @ 75 g a.i/ha (26.18/leaflet), fenpyroximate @ 30 g a.i/ha (26.61/leaflet). In untreated control as high as 109.28 eggs were recorded per leaflet and 62.44 eggs/leaflet were recorded in dicofol treated plots. Per cent reduction in egg population in these treatments (over the untreated control) was 83, 68 and 67%, respectively.

After seven days fenpyroximate treated plots harbouring <1 egg/leaflet was statistically on par with diafenthiuron @ 450 g a.i/ha treatment (Table 8). These treatments were followed by chlorfenapyr, fenazaquin, milbemectin (@ 3.75 g a.i/ha) and abamectin @6 g a.i./ha and recorded 5.5 to 10.50 egg/leaflet. Application of these acaricides accounted for 86 to 99% reduction in the number of eggs compared to untreated control.

Ten days after spray, though milbemectin treated plots recorded lowest number of eggs (19.16/leaflet), it was on par with most of the treatments except fish oil rosin soap and wettable sulphur (Table 8). Correspondingly per cent reduction in the population of eggs over treated control ranged from 68 to 84%. Untreated control recorded the highest number of 101.69 eggs/leaflet.

After fourteen days all the newer molecules, fenpyroximate (@30 g a.i/ha), milbemectin, fenazaquin, chlorfenapyr, propargite (@ 570 g a.i/ha), abamectin and diafenthiuron were statistically on par and harboured 21.06 to 36.49 eggs/leaflet compared to untreated control with 84.81 eggs/leaflet. Dicofol, wettable sulphur, mineral oil and fish oil rosin soap treatments recorded relatively more umber of eggs and were observed to be less effective (Table 8).

With second spray superiority of newer molecules especially fenpyroximate, milbemectin, chlorfenapyr, diafenthiuron and fenazaquin was evident in bringing down the population of spider mite eggs at different intervals after spray (Table 9). After 3 days though fenazaquin treated plot recorded least number of eggs 5.14/leaflet, it was on par with diafenthiuron, chlorfenapyr, milbemectin and propargite. Per cent reduction observed in the number of eggs was a maximum of 86% with fenazaquin followed by milbemectin causing 71% reduction. These treatments recorded 2.95 to 9.87, 2.53 to 6.74 and 0.35 to 2.35 eggs/leaflet after 7, 10 and 14 days, respectively and accounted for 80 to 90% reduction in egg population. In untreated control plots, 16.19 to 32.98 eggs/leaflet were recorded between 7 and 14 days.

After two applications among the newer molecules, milbemectin, fenazaquin and propargite were found significantly more effective resulting in 76 to 84 per cent reduction in the number of eggs compared to untreated control (Fig. 13).

Table 8. Bioefficacy of newer acaricides against two spotted spider mite, *Tetranychus urticae* infesting tomato at Vadagur near Kolar

Treatments	Dosage or concentration	Mean number of eggs per leaflet				
		First spray				
		Before treatment	3 DAT	7 DAT	10 DAT	14 DAT
Abamectin 1.9 EC	6 g a.i./ha.	60.02 (7.75)	43.55 (6.61)^{bcd}	10.50 (3.31)^{bc}	26.17 (5.11)^{ab}	35.69 (5.98)^{abc}
Milbemectin 1 EC	3.75 g a.i./ha.	87.25 (9.32)	34.79 (5.92)^{abcd}	8.95 (2.98)^{bc}	19.16 (4.42)^{a}	22.67 (4.77)^{a}
Chlorfenapyr 10 EC	75 g a.i./ha.	53.52 (7.34)	26.18 (5.12)^{ab}	7.14 (2.69)^{bc}	22.57 (4.71)^{a}	26.69 (5.09)^{ab}
Diafenthiuron 50 WP	450 g a.i./ha.	67.10 (8.18)	43.46 (6.56)^{bcd}	6.34 (2.37)^{ab}	21.41 (4.64)^{a}	36.49 (6.05)^{abc}
Fenazaquin 10 EC	125 g a.i./ha.	69.45 (8.31)	17.92 (4.16)^{a}	11.73 (2.97)^{bc}	28.73 (5.24)^{ab}	22.69 (4.71)^{a}
Fenpyroximate 5 SC	30 g a.i./ha.	52.99 (7.17)	26.61 (5.02)^{ab}	0.88 (1.17)^{a}	20.63 (4.48)^{a}	21.06 (4.60)^{a}
Propargite 57 EC	570 g a.i./ha.	80.57 (8.96)	39.62 (6.31)^{bcd}	19.56 (4.36)^{bcd}	24.21 (4.95)^{a}	33.74 (5.81)^{abc}
Mineral oil	1%	87.22 (9.32)	61.80 (7.87)^{cd}	19.88 (4.38)^{bcd}	34.45 (5.87)^{ab}	52.45 (7.25)^{cd}
Fish oil Rosin soap	0.5%	62.40 (7.88)	34.55 (5.91)^{abc}	44.83 (6.60)^{e}	41.84 (6.49)^{b}	61.29 (7.83)^{df}
Wettable sulphur 80 WP	2.5 g/lit.	49.74 (7.03)	53.45 (7.34)^{cd}	30.41 (5.50)^{de}	42.56 (6.53)^{b}	50.06 (7.09)^{cd}
Dicofol 18.5 EC	2.5 ml/lit.	75.43 (8.70)	62.44 (7.93)^{d}	22.41 (4.66)^{cde}	34.18 (5.86)^{ab}	42.20 (6.50)^{bcd}
Control	Water spray	72.53 (8.49)	109.28 (10.42)^{e}	88.20 (9.41)^{f}	101.69 (10.09)^{c}	84.81 (9.21)^{f}
'F' test		NS	*	*	*	*
SEM ±		(0.46)	(0.68)	(0.51)	(0.68)	(0.49)
CD at P=0.05		-	(2.01)	(1.50)	(2.01)	(1.46)

*DAT-Days After Treatment; *: significant; NS- Nonsignificant; Figures in parentheses are $\sqrt{x+0.5}$ transformed values; Treatments with same alphabetical superscript within each column are statistically on par*

Table 9. Bioefficacy of newer acaricides against two spotted spider mite, *Tetranychus urticae* infesting tomato at Vadagur near Kolar

Treatments	Dosage or concentration	Mean number of eggs per leaflet			
		Second spray			
		3 DAT	7 DAT	10 DAT	14 DAT
Abamectin 1.9 EC	6 g a.i./ha.	24.87 (5.03)^{bcd}	7.05 (2.71)^{ab}	6.33 (2.58)^{bc}	1.76 (1.50)^{abc}
Milbemectin 1 EC	3.75 g a.i./ha.	14.74 (3.71)^{ab}	2.95 (1.81)^{a}	6.74 (2.68)^{c}	0.35 (1.00)^{a}
Chlorfenapyr 10 EC	75 g a.i./ha.	13.78 (3.69)^{ab}	3.76 (2.02)^{ab}	2.99 (1.80)^{ab}	2.35 (1.68)^{bcde}
Diafenthiuron 50 WP	450 g a.i./ha.	11.51 (3.45)^{ab}	15.37 (3.75)^{bcd}	6.18 (2.53)^{abc}	4.04 (2.05)^{cde}
Fenazaquin 10 EC	125 g a.i./ha.	5.41 (2.38)^{a}	3.05 (1.83)^{a}	8.35 (2.92)^{cd}	0.74 (1.10)^{ab}
Fenpyroximate 5 SC	30 g a.i./ha.	21.50 (4.54)^{bc}	9.87 (3.03)^{abc}	2.53 (1.72)^{a}	0.69 (1.09)^{ab}
Propargite 57 EC	570 g a.i./ha.	15.78 (4.03)^{abc}	5.15 (2.34)^{ab}	6.36 (2.61)^{bc}	2.05 (1.58)^{abcd}
Mineral oil	1%	21.32 (4.59)^{bc}	21.50 (4.64)^{cd}	10.30 (3.26)^{cd}	4.47 (2.21)^{def}
Fish oil Rosin soap	0.5%	47.55 (6.88)^{e}	25.84 (4.95)^{d}	18.09 (4.29)^{e}	4.18 (2.15)^{g}
Wettable sulphur 80 WP	2.5 g/lit.	31.94 (5.62)^{cde}	22.82 (4.57)^{cd}	16.77 (4.12)^{e}	4.86 (2.27)^{ef}
Dicofol 18.5 EC	2.5 ml/lit.	30.72 (5.48)^{cde}	12.48 (3.53)^{abcd}	12.85 (3.64)^{de}	7.05 (2.71)^{f}
Control	Water spray	41.59 (6.47)^{de}	26.82 (5.19)^{d}	32.98 (5.78)^{f}	16.19 (4.05)^{g}
'F' test		*	*	*	*
SEM ±		(0.57)	(0.61)	(0.28)	(0.22)
CD at P=0.05		(1.67)	(1.78)	(0.82)	(0.65)

*DAT-Days After Treatment; *: significant ; Figures in parentheses are $\sqrt{x+0.5}$ transformed values ; Treatments with same alphabetical superscript within each column are statistically on par*

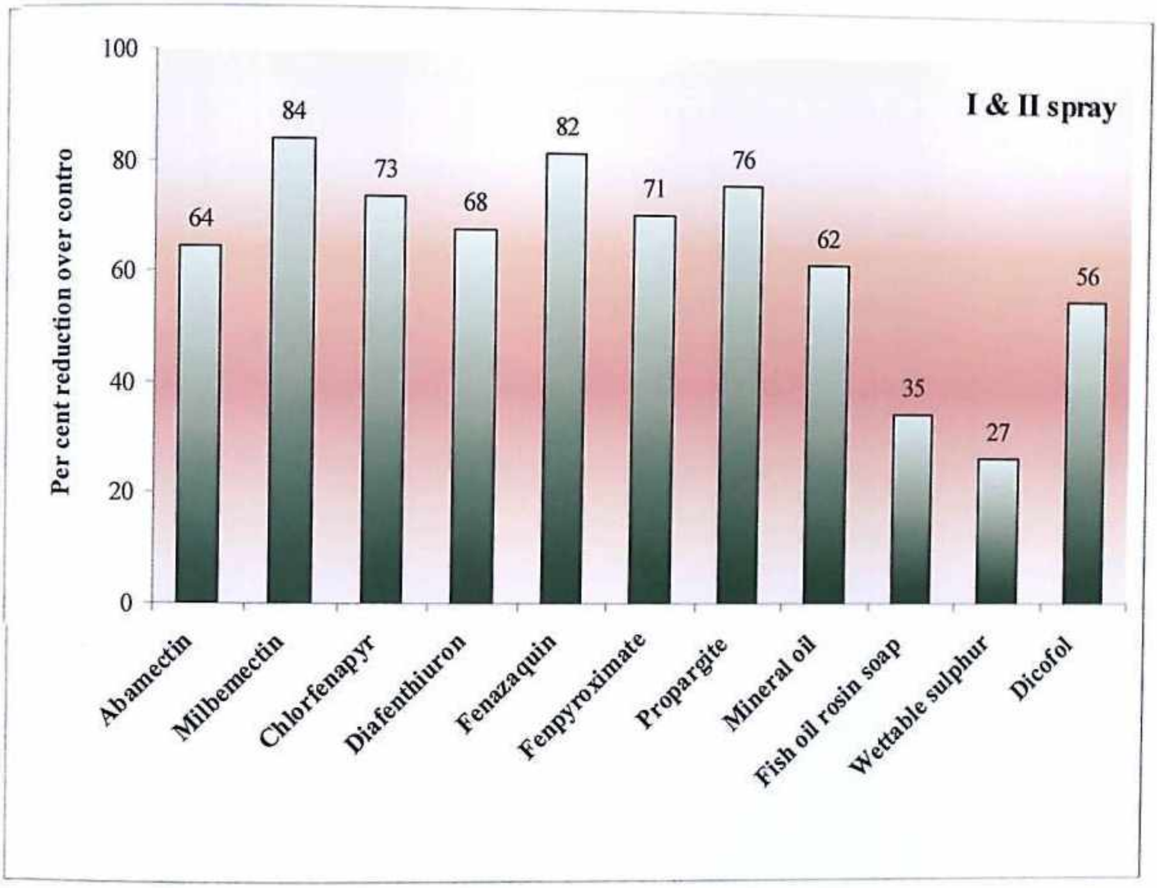


Fig. 13. Effect of newer molecules on the abundance of eggs of two spotted spider mite, *Tetranychus urticae* on tomato (Var. Abhinava)

4.3.2. Bioefficacy against active stages

Within three days of first application, chlorfenapyr, fenazaquin, diafenthiuron, fenpyroximate and propargite resulted in significant reduction (73 to 98%) in the number of active stages (0.09 to 1.13/leaflet), when untreated control had 6.68 active stages/leaflet. After 7 and 10 days newer molecules including dicofol caused significant suppression of active stages (80 to 90 %) and however, after 14 days effectiveness of milbemectin, chlorfenapyr and fenazaquin was more evident (Table 10). Between 7 and 14 days, the number of active stages in plots treated with newer molecules ranged from 0.07 to 2.56/lealet compared 4.90 to 6.81/leaflet observed in control (water spray).

The number of active stages was fairly low at the time of second application and most of the newer molecules treated plots recorded fewer number of mites (0 to 0.82/leaflet) up to 14 days compared to control with 1.21 to 1.64/leaflet (Table 11).

After two applications effectiveness of chlorfenapyr and fenazaquin was more evident resulting in 90 to 91% reduction in the population of active stages followed by propargite causing 78% reduction. Population reduction in plots treated with other newer acaricidal molecules ranged from 53to 64% (Fig. 14).

4.3.3. Bioefficacy against total mite population (eggs + active stages)

With regard to the effect of different acaricides on the total population of the mite including eggs as well as active stages, fenazaquin treated plots recorded least number of mites, 18.10/leaflet (with 84% reduction) 3 days after first application and it was statistically on par with chlorofenapyr and fenpyroximate treated plots. After 7 and 14 days fenpyroximate treatment recorded less number of mites (1.56 & 22.96/leaflet, respectively), while milbemectin treatment recorded less number of mites (20.20/leaf let) after 10 days and the corresponding reductions in mite population were 68%, 98% and 78 to 85%. However, between 7 and 14 days after first application all the synthetic newer molecules were

Table 10. Bioefficacy of newer acaricides against two spotted spider mite, *Tetranychus urticae* infesting tomato at Vadagur near Kolar

Treatments	Dosage or concentration	Mean number of active stages per leaflet				
		First spray				
		Before treatment	3 DAT	7 DAT	10 DAT	14 DAT
Abamectin 1.9 EC	6 g a.i./ha.	2.68 (1.78)	2.45 (1.71)[bcd]	1.75 (1.50)[bcd]	1.13 (1.26)[a]	2.56 (1.74)[c]
Milbemectin 1 EC	3.75 g a.i./ha.	2.63 (1.76)	2.62 (1.73)[bcd]	1.39 (1.36)[bc]	1.04 (1.23)[a]	1.04 (1.23)[ab]
Chlorfenapyr 10 EC	75 g a.i./ha.	2.17 (1.62)	0.09 (0.76)[a]	0.18 (0.82)[a]	1.08 (1.24)[a]	0.29 (0.89)[a]
Diafenthiuron 50 WP	450 g a.i./ha.	2.51 (1.72)	0.40 (0.94)[a]	0.39 (0.93)[ab]	1.31 (1.34)[ab]	2.15 (1.62)[c]
Fenazaquin 10 EC	125 g a.i./ha.	2.66 (1.76)	0.18 (0.82)[a]	0.47 (0.95)[ab]	1.25 (1.28)[ab]	1.10 (1.24)[ab]
Fenpyroximate 5 SC	30 g a.i./ha.	1.94 (1.55)	1.07 (1.22)[ab]	0.07 (1.07)[bc]	0.96 (1.20)[a]	1.89 (1.49)[bc]
Propargite 57 EC	570 g a.i./ha.	3.35 (1.95)	1.13 (1.27)[abc]	2.02 (1.57)[cd]	0.93 (1.19)[a]	1.65 (1.46)[bc]
Mineral oil	1%	2.68 (1.78)	3.87 (2.03)[d]	1.72 (1.48)[bcd]	1.95 (1.55)[abc]	2.49 (1.72)[c]
Fish oil Rosin soap	0.5%	2.56 (1.71)	1.77 (1.49)[bc]	4.06 (2.05)[d]	2.26 (1.66)[bd]	2.67 (1.77)[c]
Wettable sulphur 80 WP	2.5 g/lit.	2.16 (1.61)	2.74 (1.77)[cd]	1.99 (1.55)[cd]	3.06 (1.87)[c]	1.50 (1.41)[bc]
Dicofol 18.5 EC	2.5 ml/lit.	3.68 (2.02)	1.74 (1.49)[bc]	1.55 (1.36)[bc]	2.04 (1.57)[abc]	1.78 (1.49)[bc]
Control	Water spray	3.23 (1.91)	6.68 (2.66)[e]	6.81 (2.66)[e]	7.53 (2.81)[d]	4.90 (2.32)[d]
'F' test		NS	*	*	*	*
SEM ±		(0.13)	(0.18)	(0.19)	(0.13)	(0.12)
CD at P=0.05		-	(0.52)	(0.58)	(0.38)	(0.37)

*DAT-Days After Treatment; *: significant; NS- Nonsignificant; Figures in parentheses are $\sqrt{x+0.5}$ transformed values; Treatments with same alphabetical superscript within each column are statistically on par*

Table 11. Bioefficacy of newer acaricides against two spotted spider mite, *Tetranychus urticae* infesting tomato at Vadagur near Kolar

Treatments	Dosage or concentration	Mean number of active stages per leaflet			
		Second spray			
		3 DAT	7 DAT	10 DAT	14 DAT
Abamectin 1.9 EC	6 g a.i./ha.	0.38 (0.93)[abc]	1.09 (1.24)[bc]	0.33 (0.90)[ab]	0.82 (1.14)[cde]
Milbemectin 1 EC	3.75 g a.i./ha.	0.26 (0.86)[ab]	0.67 (1..08)[ab]	0.38 (0.94)[ab]	0.63 (1.05)[bcd]
Chlorfenapyr 10 EC	75 g a.i./ha.	0.00 (0.70)[a]	0.03 (0.72)[a]	0.34 (0.91)[ab]	0.01 (0.71)[a]
Diafenthiuron 50 WP	450 g a.i./ha.	0.08 (0.76)[a]	0.76 (1.11)[ab]	0.28 (0.88)[ab]	2.71 (1.77)[f]
Fenazaquin 10 EC	125 g a.i./ha.	0.00 (0.70)[a]	0.00 (0.70)[a]	0.29 (0.89)[ab]	0.02 (0.72)[ab]
Fenpyroximate 5 SC	30 g a.i./ha.	0.33 (0.90)[ab]	0.69 (1.07)[ab]	0.14 (0.79)[a]	0.39 (0.94)[abc]
Propargite 57 EC	570 g a.i./ha.	0.11 (0.77)[a]	0.58 (1.03)[ab]	0.31 (0.90)[ab]	0.27 (0.87)[ab]
Mineral oil	1%	0.26 (0.87)[ab]	2.15 (1.58)[cd]	0.47 (0.98)[abc]	1.52 (1.40)[e]
Fish oil Rosin soap	0.5%	0.96 (1.20)[d]	3.05 (1.82)[d]	0.90 (1.18)[c]	1.02 (1.22)[cde]
Wettable sulphur 80 WP	2.5 g/lit.	0.89 (1.17)[cd]	1.42 (1.37)[bc]	0.55 (1.02)[bc]	1.22 (1.28)[de]
Dicofol 18.5 EC	2.5 ml/lit.	0.70 (1.09)[bcd]	1.06 (1.22)[bc]	0.62 (1.05)[bc]	0.88 (1.16)[cde]
Control	Water spray	1.21 (1.26)[d]	1.27 (1.32)[bc]	1.56 (1.40)[d]	1.64 (1.45)[ef]
'F' test		*	*	*	*
SEM ±		(0.09)	(0.15)	(0.07)	(0.11)
CD at P=0.05		(0.26)	(0.44)	(0.20)	(0.33)

*DAT-Days After Treatment; *: significant; NS- Nonsignificant; Figures in parentheses are $\sqrt{x+0.5}$ transformed values; Treatments with same alphabetical superscript within each column are statistically on par*

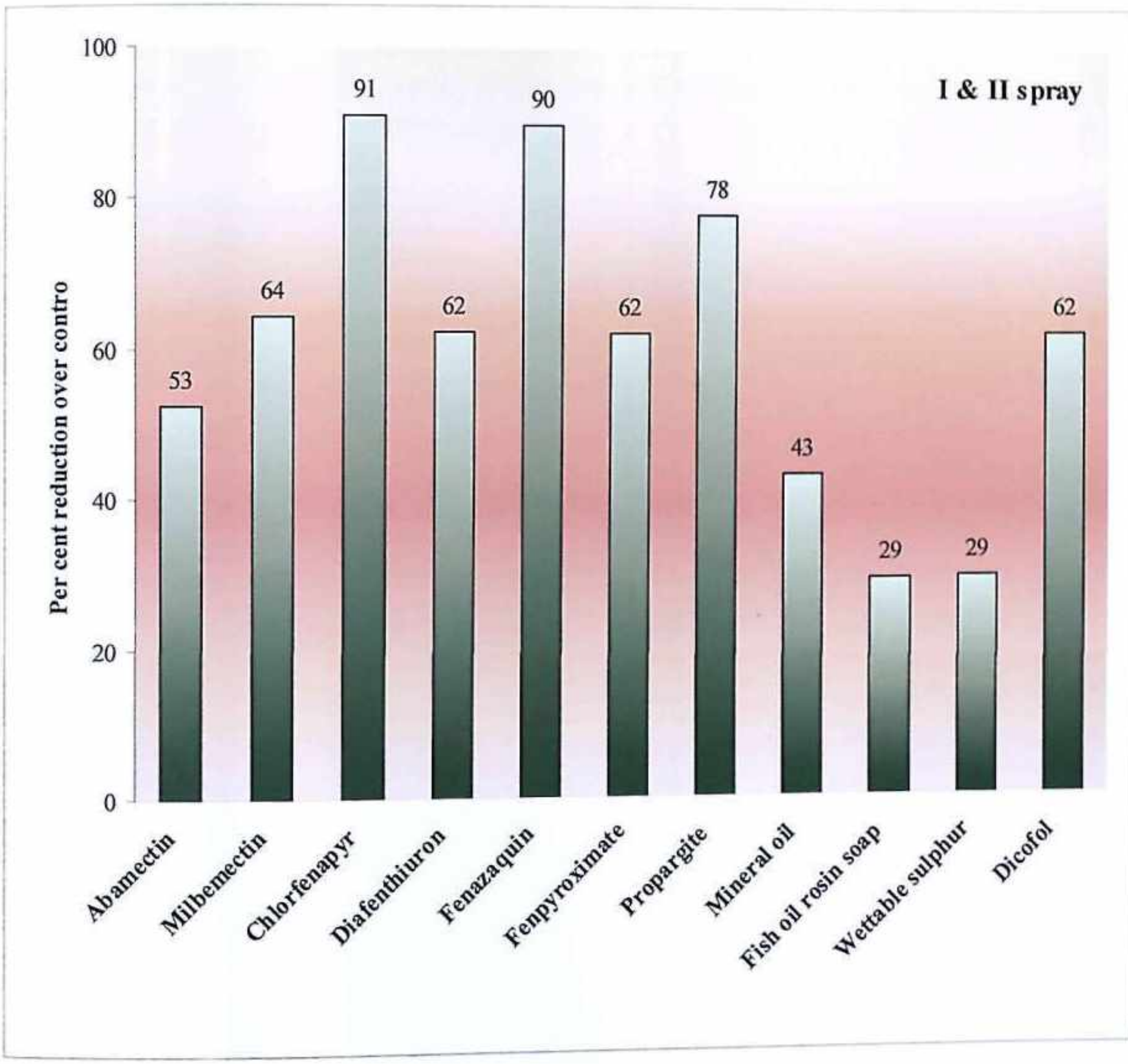


Fig. 14. Effect of newer molecules on active stages of two spotted spider mite, *Tetranychus urticae* on tomato ((Var. Abhinava)

comparable in their efficacy and resulted in 70 to 80% reduction in total mite population compared to water sprayed control (Table 12). During this period the number of mites in control and plots treated with newer molecules ranged from 89.73 to 95.02/leaflet and 1.56 to 38.65 mite/leaflet, respectively. The effect of mineral oil 1% was only moderate with 21. 61 to 54.95 number of mites (Table 12).

With second application also newer molecules showed their superiority over conventional acaricides, dicofol, wettable sulphur and untreated control in suppressing the mite population up to 14 days. At different intervals after the application, though all the newer molecules were either comparable or on par in their effect, fenazaquin, fenpyroximate, milbemectin and chlorfenapyr treated plots harboured relatively fewer number of mites (0.76 to 8.65, 1.09 to 21.84, 1.18 to 15.00 and 2.36 to 13.78, respectively). The number of mites is untreated control ranged from 17.84 to 42.80/leaflet during this period.

The overall effect of two applications of newer synthetic molecules, milbemectin, fenazaquin, propargite, chlorfenapyr and fenpyroximate in bringing down the total population of mites (including eggs and active stages) was significant compared to conventional chemicals like dicofol, wettable sulphur (Fig. 15). These newer molecules caused 70 to 83% reduction in the total mite population compared to 56 to 61% reduction observed with dicofol and mineral oil treatments.

Table 12. Bioefficacy of newer acaricides against two spotted spider mite, *Tetranychus urticae* infesting tomato at Vadagur near Kolar

Treatments	Dosage or concentration	Mean number of mites (eggs + active stages) per leaflet				
		First spray				
		Before treatment	3 DAT	7 DAT	10 DAT	14 DAT
Abamectin 1.9 EC	6 g a.i./ha.	62.70 (7.92)	46.01 $(6.80)^{cde}$	12.26 $(3.56)^{bcd}$	27.31 $(5.22)^{abcd}$	38.26 $(6.20)^{abc}$
Milbemectin 1 EC	3.75 g a.i./ha.	89.86 (9.33)	37.43 $(6.13)^{bcd}$	10.35 $(3.21)^{abcd}$	20.20 $(4.54)^{a}$	23.75 $(4.87)^{a}$
Chlorfenapyr 10 EC	75 g a.i./ha.	55.72 (7.48)	26.28 $(5.13)^{ab}$	7.33 $(2.73)^{abc}$	20.36 $(4.53)^{a}$	27.27 $(5.15)^{a}$
Diafenthiuron 50 WP	450 g a.i./ha.	69.75 (8.34)	43.86 $(6.59)^{cd}$	6.74 $(2.45)^{ab}$	22.74 $(4.78)^{abc}$	38.65 $(6.23)^{abc}$
Fenazaquin 10 EC	125 g a.i./ha.	72.12 (8.47)	18.10 $(4.28)^{a}$	12.18 $(3.03)^{abcd}$	29.98 $(5.35)^{abcde}$	23.80 $(4.83)^{a}$
Fenpyroximate 5 SC	30 g a.i./ha.	54.94 (7.30)	27.70 $(5.12)^{ab}$	1.56 $(1.43)^{a}$	21.59 $(4.59)^{ab}$	22.96 $(4.81)^{a}$
Propargite 57 EC	570 g a.i./ha.	83.93 (9.14)	40.76 $(6.40)^{bcd}$	21.58 $(4.58)^{cde}$	25.14 $(5.04)^{abc}$	35.39 $(5.95)^{ab}$
Mineral oil	1%	89.92 (9.47)	64.88 $(8.06)^{e}$	21.61 $(4.57)^{cde}$	36.71 $(6.06)^{cde}$	54.95 $(7.42)^{cd}$
Fish oil Rosin soap	0.5%	64.97 (8.04)	36.32 $(6.06)^{bc}$	48.89 $(6.88)^{f}$	44.11 $(6.67)^{de}$	63.97 $(7.99)^{d}$
Wettable sulphur 80 WP	2.5 g/lit.	51.90 (7.19)	56.01 $(7.52)^{de}$	32.39 $(5.67)^{ef}$	45.63 $(6.75)^{e}$	51.57 $(7.19)^{bcd}$
Dicofol 18.5 EC	2.5 ml/lit.	79.12 (8.89)	64.18 $(8.04)^{e}$	23.96 $(4.81)^{de}$	36.23 $(6.03)^{bcde}$	43.99 $(6.64)^{bcd}$
Control	Water spray	75.76 (8.70)	115.9 $(10.73)^{f}$	95.02 $(9.76)^{g}$	109.22 $(10.46)^{f}$	89.73 $(9.48)^{e}$
'F' test		NS	*	*	*	*
SEM ±		(0.46)	(0.49)	(0.70)	(0.49)	(0.49)
CD at P=0.05		-	(1.44)	(2.06)	(1.45)	(1.45)

*DAT-Days After Treatment; *: significant; NS- Nonsignificant; Figures in parentheses are $\sqrt{x+0.5}$ transformed values ; Treatments with same alphabetical superscript within each column are statistically on par*

Table 13. Bioefficacy of newer acaricides against two spotted spider mite, *Tetranychus urticae* infesting tomato at Vadagur near Kolar

Treatments	Dosage or concentration	Mean number of mites (eggs + active stages) per leaflet			
		Second spray			
		3 DAT	7 DAT	10 DAT	14 DAT
Abamectin 1.9 EC	6 g a.i./ha.	25.26 $(5.07)^{bcde}$	8.15 $(2.90)^{abc}$	6.66 $(2.64)^{bc}$	2.58 $(1.74)^{ab}$
Milbemectin 1 EC	3.75 g a.i./ha.	15.00 $(3.74)^{ab}$	3.63 $(2.00)^{ab}$	7.13 $(2.70)^{bc}$	1.18 $(1.29)^{a}$
Chlorfenapyr 10 EC	75 g a.i./ha.	13.78 $(3.69)^{ab}$	3.79 $(2.03)^{ab}$	3.34 $(1.90)^{ab}$	2.36 $(1.69)^{a}$
Diafenthiuron 50 WP	450 g a.i./ha.	11.59 $(3.46)^{ab}$	16.14 $(3.85)^{cde}$	6.47 $(2.59)^{abc}$	6.75 $(2.63)^{c}$
Fenazaquin 10 EC	125 g a.i./ha.	5.41 $(2.38)^{a}$	3.05 $(1.83)^{a}$	8.65 $(2.96)^{cd}$	0.76 $(1.11)^{a}$
Fenpyroximate 5 SC	30 g a.i./ha.	21.84 $(4.57)^{bcd}$	10.57 $(3.13)^{abcd}$	2.67 $(1.76)^{a}$	1.09 $(1.26)^{a}$
Propargite 57 EC	570 g a.i./ha.	15.89 $(4.04)^{abc}$	5.74 $(2.47)^{abc}$	6.68 $(2.67)^{bc}$	2.33 $(1.67)^{a}$
Mineral oil	1%	21.57 $(4.62)^{bcd}$	23.66 $(4.86)^{de}$	10.78 $(3.33)^{cd}$	5.99 $(2.54)^{c}$
Fish oil Rosin soap	0. 5%	48.52 $(6.95)^{f}$	28.89 $(5.28)^{e}$	19.01 $(4.40)^{e}$	5.22 $(2.37)^{bc}$
Wettable sulphur 80 WP	2.5 g/lit.	32.84 $(5.70)^{def}$	24.25 $(4.73)^{de}$	17.33 $(4.19)^{e}$	6.08 $(2.54)^{c}$
Dicofol 18.5 EC	2.5 ml/lit.	30.76 $(5.50)^{cdef}$	13.55 $(3.66)^{bcde}$	13.45 $(3.72)^{de}$	7.94 $(2.86)^{c}$
Control	Water spray	42.80 $(6.36)^{ef}$	28.09 $(5.32)^{e}$	34.55 $(5.91)^{f}$	17.84 $(4.24)^{d}$
'F' test		*	*	*	*
SEM ±		(0.57)	(0.62)	(0.28)	(0.21)
CD at P=0.05		(1.67)	(1.81)	(0.83)	(0.63)

*DAT-Days After Treatment; *: significant; Figures in parentheses are $\sqrt{x+0.5}$ transformed values; Treatments with same alphabetical superscript within each column are statistically on par*

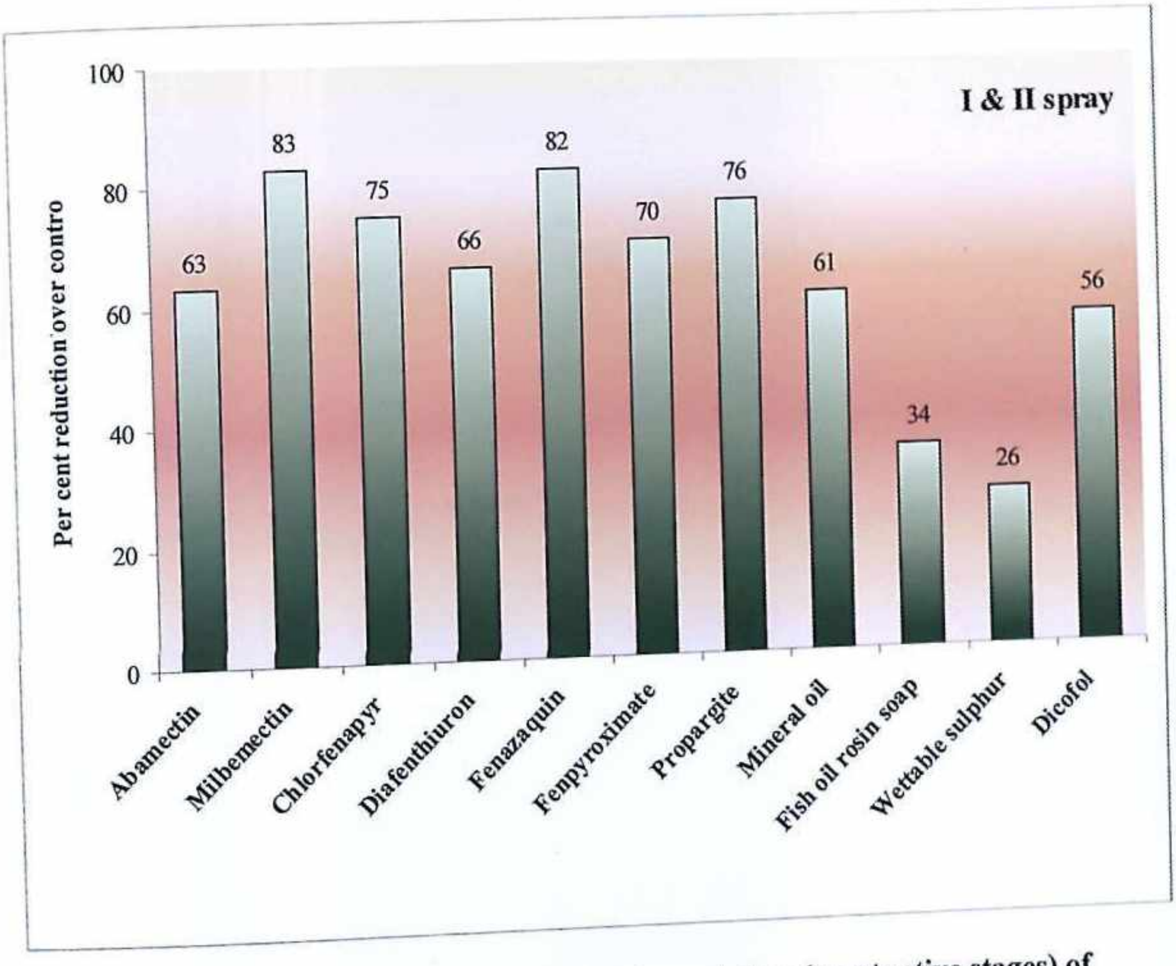


Fig. 15. Effect of newer molecules on total population (eggs+active stages) of two spotted spider mite, *Tetranychus urticae* on tomato (Var.Abhinava)

DISCUSSION

V. DISCUSSION

Investigations were carried out, **i)** To establish base-line values for the susceptibility of laboratory population of *T. urticae* to conventional acaricides like dicofol, wettable sulphur and newer acaricides like abamectin, diafenthiuron, fenazaquin and propargite, **ii)** To assess the frequency and intensity of resistance to these acaricides in *T. urticae* populations on tomato from Bangalore and Kolar districts, and **iii)** To ascertain the field efficacy of newer acaricidal molecules against *T. urticae* on tomato.

The results of these investigations are discussed in this chapter.

When laboratory population of *T. urticae* was exposed to different acaricides in successive generations (from 5th to 38th generation), the susceptibility level increased with all the acaricides tested. The decline in LC_{50} values over different generations indicated progressive susceptibility of the laboratory population to acaricides.

For wettable sulphur the LC_{50} value of 211 ppm in the 15th generation decreased to 114 ppm by the 38th generation. With dicofol LC_{50} got reduced from 183 ppm to 0.1 ppm between 5th and 38th.

The susceptibility of laboratory reared *T. urticae* to abamectin increased with the corresponding decrease in the LC_{50} values from 0.5 ppm to 0.1 ppm as the generation cycle progressed from 25th to 38th generation.

Similarly, LC_{50} values of diafenthiuron, fenazaquin and propargite which were 2.7 ppm, 5.1 ppm and 3 ppm, respectively in 15th generation for laboratory reared *T. urticae* population, and correspondingly reduced to 0.1 ppm, 0.1 ppm and 0.3 ppm in the 38th generation.

The susceptible laboratory culture of *T. urticae* was successfully established in the laboratory in one year period from February 2007 to February

2008 and this mite culture was used a susceptible reference culture. The LC_{50} values determined for the 38th generation of *T. urticae* laboratory population was considered and used as the base-line values for quantifying acaricide resistance in the field populations of *T. urticae* on tomato from different locations in Bangalore and Kolar districts.

Concentration - mortality responses in laboratory populations of *T. urticae* to different acaricides were constructed during 5th, 15th, 25th and 38th generation and illustrated (Fig. 1 to 6).

With acaricides dicofol, fenazaquin and propargite, progressive increase in slope values in dose-mortality regression lines between 15th and 25th generation was evident (Fig. 2, 5 & 6).

5.1. Assessment of acaricide resistance in *T. urticae* populations from tomato

The assessment of level of acaricide resistance in a mite pest population is regarded as a prerequisite for successful resistance management.

Young *et al.* (2004) grouped the intensity of resistance to different acaricides observed in *T. urticae* as : i) <10 Resistance Ratio - Low level, ii) 11-40 RR - Moderate level and iii) >40 RR - High level of resistance. In the present study the levels of resistance are categorized as ; RR : < 10 – Low, RR : 10 to 50 – Moderate level, RR : >50 – High level of resistance.

5.1.1. Resistance to wettable sulphur

In Bangalore district, *T. urticae* populations from tomato showed low level of resistance to wettable sulphur (7 to 26 folds) compared to the populations from Kolar district (with 3 to 38 folds). The intensity of resistance to wettable sulphur increased within the cropping season at different locations in Bangalore district. Though the usage of wettable sulphur against spider mites on tomato crop in this region is rare, still the selection pressure exerted due to the application of other acaricidal molecules might have induced these mites to show low to moderate level of resistance to wettable sulphur or the resistance might have remained stable at low to moderate levels. But in Kolar district the level of resistance noticed during the early part of the growing season got increased slightly and declined further (Table 2).

Sridhar and Jhansi Rani (2007) recorded 2 to 12 folds resistance to wettable sulphur in *T. urticae* populations from polyhouse roses in Delhi, Pune, Bangalore and Hosur (Tamil Nadu).

5.1.2. Resistance to dicofol

T. urticae population sampled from Vadagur village of Kolar district during December 2007 expressed the highest level of resistance to dicofol *i.e.*, 6491 folds. In all the locations the level of dicofol resistance followed a increasing trend as the cropping season advanced. This clearly indicated that enhancement in the resistance to dicofol was the result of selection pressure imposed due to acaricidal application(s) in the early part of mite infestation. Dennehy *et al.* (1987) opined that an upward shift in acaricide resistance in the mite population during the season is the result of increase in the frequency of resistant individuals.

In Kolar district, the level of resistance to dicofol noticed in the early part of the cropping season was similar (500 and 512 folds) at both the locations and also the resistance increased to the similar levels in the succeeding months ([illegible] folds and 3655 folds, respectively).

In Vadagur population increase in dicofol resistance was evident from June onwards to reach a peak of 6491 folds in December 2007 and it declined to 6045 folds in the following month of January 2008 (Table 3).

Varying level of resistance to dicofol in *T. urticae* populations has been reported by earlier workers, Dennehy *et al.* (1983) ([illegible] folds on cotton), Jacobs *et al.* (1988) (100-1000 folds in commercial green house), Dennehy and Granett

(1984 a&b) (573 folds on cotton), Cheng and Pan, 1994 (1791 folds on apple), Shaila (1999) (4 folds on open cultivated rose) and Sridhar and Jhansi Rani (2007) (2-3 folds on polyhouse rose). This variation in the resistance levels is attributed to the differences in the bioassay techniques adapted, susceptibility of the reference population (laboratory) and the host crop of the field sampled population, the type of crop cultivation *etc*.

Martinson *et al*. (1991) recorded 2-3 folds higher LC_{50} values of dicofol for *T. uticae* when exposed to discontinuous dicofol residues compared to continuous residues on leaves in laboratory bioassays. Thus they opined that dicofol resistance was completely dominant under field conditions in contrast with its recessive inheritance in the laboratory assays.

The expression of varied levels of resistance in *T. urticae* noticed in the present study might be due to the fact the dicofol is still being used against this phytophagous mite pest on one or the crop. This is because the resistance to dicofol in *T. urticae* has been considered as unstable in the absence of selection pressure (Fergusson - Kolmes *et al*., 1991). But Overmeer *et al*. (1975) opined that inspite of discontinued use of dicofol for several years (>7 years), resistance to dicofol was still present in populations from rose grown in glass houses. They stated, though the process of resistance break down which occur due to immigration of susceptible mites from other areas and by possible incompetitiveness of resistance individuals, is a very slow process. Also reversion to susceptibility in practice is apparently very low, so the possibility of using dicofol in rotational spray system may be ruled out.

5.1.3. Resistance to abamectin

Resistance to abamectin was studied in *T. urticae* populations on tomato crop from Vadagur village of Kolar district. When compared with the LC_{50} of abamectin for susceptible laboratory population (0.00001% a.i.), the extent of resistance in the field population was fairly low *i.e*, 4 – 8 folds during December

(2007) - February (2008). The reported instances of resistance in *T. urticae* to abamectin are sparse. However, the possibility of cross resistance to Avermectin (MK 936 EC 18) in dicofol resistant *T. urticae* population from apple was ruled out by Linda *et al.* (1991). Sato *et al.* (2004) reported insignificant cross resistance to Avermectins (abamectin and milbemectin) in fenpyroximate resistant *T. urticae* populations sampled from commercial strawberry fields in Brazil. The usage of such acaricides for which no cross resistance has been observed was suggested as one of the strategies to prolong the efficacy of an acaricide in the field. Young *et al.* (2004) reported that the *T. urticae* population extremely resistant to fenpyroximate with a Resistance Ratio of 252 folds selected in the laboratory for 20 generations exhibited low level of resistance to milbemectin (Resistance Ratio <10) and moderate level of resistance to abamectin (Resistance Ratio 11–40).

5.1.4. Resistance to diafenthiuron

As with abamectin, no reports are available on the evidences of diafenthiuron resistance in *T. urticae*. Moderate level of resistance to diafenthiuron was observed both in Bangalore (14–37 folds) and Kolar districts (18–47 folds) especially during the kharif season (June to October 2007). But in Vadagur of Kolar district, when the mite sampling on tomato was continued and assessed for diafenthiuron resistance, it was found to increase to 79 folds and 67 folds during December 2007 and February 2008, respectively. This clearly indicated the progressive accumulation of diafenthiuron resistant mites on tomato crop in Vadagur area of Kolar district.

5.1.5. Resistance to fenazaquin

T. urticae population from tomato exhibited low to high level of resistance (5 to 168 folds) to fenazaquin. When the mite populations from tomato crop cultivated between June and December months were sampled at different intervals, the extent of resistance which was at the lower level (8–13 folds) got shifted to the moderate level (16–32 folds). As observed with diafenthiuron, mite population from Vadagur expressed high level of resistance when sampled in the following months of December (2007) and February (2008). This evidently showed increase in the proportion of fenazaquin resistant individuals on succeeding tomato crops, which were able to tolerate the higher doses. As a result the LC_{50} values were high, 0.00168 to 0.00249% a.i. compared to previously determined values of 0.00008 to 0.00019% a.i.

The level of acaricide resistance likely to vary greatly with the host crop harbouring the mite population (probably due to selection pressure resulting from acaricide application on the crop) and the referral susceptible population. This is evident from the findings of earlier workers.

Devine *et al.* (2001) observed that a strain of *T. urticae* from hops exhibited varying levels of resistance to METI (mitochondrial electron transport inhibitor) acaricides, like tebufenpyrad, pyridaben, fenazaquin and fenpyroximate, of which level of resistance to fenazaquin was high *i.e*, 168 folds.

In *T. urticae* population from apple in Southern France, Romain *et al.* (2003) recorded moderate level of resistance to fenazaquin, as Resistance Ratios ranged from 20 to 29.

When Young and co-workers (2004 and 2006) studied fenpyroximate and pyridaben resistant populations of *T. urticae* (selected over 20 generations in the laboratory) for their cross resistance to another acaricide of similar mode of action *i.e.,* fenazaquin, the levels of resistance noticed were low (RR<10) and medium (RR 10–40), respectively.

As observed in the present study with *T. urticae* population on tomato, resistance to METI-acaricides has been reported from Belgium (Bylemanns and Meurrens, 1997) and Australia (Herron and Rophail, 1998) on crops like strawberry and apple.

5.1.6. Resistance to propargite

When sampled between June and October months, the ability of *T. urticae* populations on tomato to resist the toxic doses of propargite ranged from 4 to 12 folds and the corresponding LC_{50} values were 1.2 ppm to 8.3 ppm. The level of resistance recorded on the kharif season crop in Bangalore and Kolar districts was almost to the same extent. However, in Vadagur of Kolar district, the level of tolerance though increased to 28 folds during December, it remained stable further.

Compared to median lethal concentration values of 1.2 ppm to 8.3 ppm determined for *T. urticae* population on tomato in the present study, varying levels of resistance to propargite in *T. urticae* populations from cotton (635 ppm – 8104 ppm), carnation (1464 ppm) and almonds (316 ppm) have been recorded by Dennehy *et al.* (1987), Cheng and Pan (1994), Estrada-Cotero and Sanchez-Galvez (1990) and Keena and Granett (1990). These differences in tolerance to propargite may be attributed the extent of selection pressure (or usage of propargite against *T. urticae*), host crop as well as the bioassay techniques adapted.

5. 2. Bioefficacy of newer molecules against *T. urticae* on tomato

After the first application, milbemectin (3.75 g a.i./ha), fenazaquin (125 g a.i./ha), fenpyroximate (30 g a.i./ha), propargite (570 g a.i./ha), chlorfenapyr (75g a.i./ha) and diafenthiuron (450 g a.i./ha) were significantly more effective in bringing down the population of spider mite eggs by 70 – 82% compared to other treatments like, abamectin (64% reduction), dicofol (60% reduction), wettable sulphur (33% reduction), mineral oil (64% reduction) and fish oil rosin soap (43% reduction). With second application also similar trend was observed and the extent of reduction in the population of eggs in plots treated with newer molecules ranged from 66 to 87%, while in dicofol treatment reduction was only 51%. Over two applications, milbemectin, fenazaquin, propargite, chlorfenapyr and fenpyroximate were found superior in reducing the egg population more than 70% compared to 57% reduction noticed with dicofol application (Fig. 13).

With regard to the effectiveness in field against active stages, the order of efficacy was chlorfenapyr, fenazaquin, propargite, diafenthiuron, fenpyroximate and milbemectin causing 91%, 85%, 78%, 77%, 72% and 71% reduction, respectively in the first application. But with second application the efficacy of only first three molecules was significant. With two applications, chlorfenapyr, fenazaquin and propargite proved their superiority in bringing down the number of active stages causing 78 to 91% reduction over untreated control. With dicofol applications, reduction in the population of active stages was only 62% (Fig. 14).

When the field efficacy of newer molecules against total population including eggs and active stages was analysed after the first application, the extent of reduction ranged between 73% and 81% in milbemectin, fenazaquin, fenpyroximate, propargite, chlorfenapyr and diafenthiuron treated plots. But with second application superiority in reducing the population was apparent with only fenazaquin (with 86% reduction), milbemectin (with 84% reduction) and propargite (with 80% reduction). In dicofol treatment 61% and 51% reduction in mite population was observed with first and second applications, respectively. However, the overall efficacy of two applications on the total mite population revealed the superiority of milbemectin and fenazaquin treatments, which resulted in 82-83% reduction over the untreated control. Propargite, chlorfenapyr and fenpyroximate were next in the order of efficacy causing 70-76% reduction in mite population compared to 56% reduction noticed with dicofol. Diafenthiuron, abamectin and mineral oil 1% were able to bring down the population by 61-66%.

Though ample literature on control or management of spider mites with newer synthetic acaricides in varied crop situations is available, pertinent references on the control two spotted spider mite on tomato are few. Acaricides like dicofol, abamectin, fenazaquin, fenpyroximate, diafenthiuron, propargite *etc.* have been evaluated against *T. urticae* on crops like tomato and cucumber (Aji, 2005 ; Szwejda, 1993 & 1994 ; Undurraga and Dybas, 1998 ; Atanasov *et al.*, 1995), polyhouse rose (Aguiar *et al.*, 1993 & 1995 ; Sekulic *et al.*, 1998 ; Onkarappa, 1999), sugarbeet (Legrand *et al.*, 1999), ornamentals (Green & Dybas, 1984), strawberry (Antonin *et al.*, 1997 ; Nicotina & Ernesto, 1998), cotton (El-Banhawy & Anderson, 1985 ; Vostrel, 1996), apple–peer-peach (Allen *et al.*, 1997 ; Curkovic *et al.*, 1999 ; Choi *et al.*, 1997) and vegetables (Masis and Aguilar, 1990) in India, Poland, United States of America, Mexico, Argentina, South Africa, Bulgaria, Switzerland, Italy and Korean Republic.

Significant reduction in the population of eggs *i.e.*, 84% (over two applications) in milbemectin treated plots (Fig. 13) observed in the present study is supported by the findings of Aji (2005), who recorded in the laboratory the lowest LC_{50} value of milbemectin against *T. urticae* eggs (3.77ppm) compared to fenpyroximate, abamectin and fenazaquin. In the present study effect of fenazaquin @125g a.i./ha was more significant as it resulted in 82% reduction in mixed stage population of *T. urticae* on tomato (Fig. 15). As indicated in the earlier reports effective period of fenazaquin varied with the crop, growing conditions and the dose/concentration used. Sekulic *et al.* (1998) noticed better efficacy of fenazaquin at 80-120mg/litre against *T. urticae* on cucumber and tomato for 7 days only under glasshouse conditions. Legrand *et al.* (1999) could record the effectiveness of fenazaquin up to one month on sugarbeet. Application of fenazaquin at 75 a.i./100 litres of water offered good control of *T. urticae* on green house strawberry (Nicotina and Ernesto, 1998), while, at 0.06% concentration it was more effective on *Humulus lupulus* (Vostrel, 1996). *T. urticae* infested strawberry in open cultivated and covered fields as well as field cultivated Clementines were better protected by the application of fenazaquin (Antonin *et al.*, 1997 ; Aucejo *et al.*, 2003).

Application of propargite @ 570 g a.i./ha or fenpyroximate @ 30 g a.i./ha or fenpyroximate @ 30 g a.i./ha or chlorfenapyr @ 75 g a.i./ha twice at two weeks intervals against *T. urticae* on tomato in the present study which would result in 70–76% reduction in the mixed stage population of the mite is in line with the findings of Atanasov *et al.* (1995), who also observed maximum protection of two spotted spider mite infested green house tomatoes when newer compounds like propargite, fenpyroximate and diafenthiuron were used judiciously along with phytoseiid mite predator, *Phytoseiulus persimilis* in Bulgaria. Choi *et al.* (1997) also recorded greater efficacy of propargite and fenpyroximate against eggs and active females of *T. viennensis* on cherry, peach and apple orchards in Korean republic.

Promising feature of fenpyroximate against two spotted spider mite on tomato noticed in the present study is in line with reports of Vostrel (1996) on *Humulus lupulus* and that of Curkovic *et al.* (1999) on European red mite infested apple and pear crops.

Fengying Guo *et al.* (1998) suggested the following for the successful management of mite pests in the event of acaricide resistance ; i) use of highly effective acaricide at initial stages of mite infestation, ii) use of only selective acaricides to conserve natural enemies and to support their role in natural pest control and iii) rotational use of acaricides with different mode of action over a long period of time to improve susceptibility in the resistant population as compared to repeated use of the same acaricide. This also helps to extend the performance of an acaricide in the field.

It is revealed from the present study that *T. urticae* populations on tomato from Vadagur has very high level of resistance to dicofol (Table 3 ; Fig. 8D) and it is evidenced by the reduced level of control obtained with dicofol application (Table 12 -13). Dicofol application could reduce the mite population by only 56% (Fig. 15). In this context, the evaluation of newer compounds like milbemectin, fenazaquin, fenpyroximate, propargite and chlorfenapyr undertaken in the present study to manage the dicofol resistant two spotted spider mite population in Vadagur is more relevant and these acaricides might be recommended for use as they were found promising.

Among the other acaricides for which the extent of resistance in *T. urticae* populations from Vadagur was studied, abamectin and propargite recorded relatively low level of resistance. Thus milbemectin and propargite, which were found more effective in the present field trial might be used more conveniently as Linda *et al.* (1991) reported no significant differences in the responses of dicofol resistant and susceptible populations of *T. urticae* to propargite and avermectin compounds. Supportingly, Young *et al.* (2004) and Sato *et al.* (2004) have detected negligible or very low level of cross resistance in *T. urticae* populations for acaricides like, propargite, milbemectin and fenpyroximate.

SUMMARY

VI. SUMMARY

Investigations were carried out during 2006-08 on the determination of base-line values for susceptibility of laboratory population of *T. urticae* to selected acaricides namely, wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite, to assess the frequency and level of resistance to these acaricides in *T. urticae* populations on tomato from Bangalore and Kolar districts, and to evaluate newer acaricidal molecules against this mite pest in farmer's field in Vadagur of Kolar district. The results of the laboratory studies conducted in the Acarology Unit of Dept. of Agricultural Entomology, University of Agril. Sciences, GKVK, Bangalore and the field investigations in farmer's fields in Bangalore and Kolar districts are briefly summarized here under.

Population of *T. urticae* was maintained continuously in the laboratory for over a period of one year from February 2007 to February 2008 without exposing it to any acaricides. The susceptibility of this laboratory population increased over successive generations (from 5th to 38th generation) to all the acaricides tested, wettable sulphur, dicofol, abamectin, diafenthiuron, fenazaquin and propargite. T his laboratory population was used as the reference susceptible population and the median lethal concentration values (LC_{50}) of acaricides for this laboratory population at the 38th generation were determined as the base-line values. The LC_{50} values determined for this susceptible laboratory population (reference population) were 114 ppm for wettable sulphur, 0.1 ppm each for dicofol, abamectin, fenazaquin & diafenthiuron and 0.3 ppm for propargite.

The level of resistance to wettable sulphur in *T. urticae* populations from tomato crop ranged from 7 to 30 folds (Resistance Ratio 6.7 to 30.3) in Bangalore district and 3 to 38 folds (Resistance Ratio 3.2 to 38.1) in Kolar district. The level of resistance ranged from low to moderate.

For dicofol the intensity of resistance was high in both Bangalore (767 to 3690 folds) and Kolar districts (500 to 6491 folds). The resistance ratio was maximum of 6491 during December 2007 for spider mite population from Vadagur in Kolar district, where the tomato crop is grown continuously throughout the year under irrigated conditions and the farmers also resort to intensive plant protection measures against pests and diseases of tomato.

For abamectin the extent of resistance exhibited by *T. urticae* population from Kolar district was low as the resistance ratio was less than 10 (RR 4 to 8).

For diafenthiuron a moderate level of resistance was noticed in both Bangalore and Kolar districts (RR of 14-37 and 18-47, respectively). However, the resistance increased to higher levels of 67 and 79 folds, in mite population sampled during the rabi season months, December (2007) and February (2008).

Two spotted spider mite population from Bangalore and Kolar districts showed a progressive development of resistance to fenazaquin from a low to moderate level (RR 5 to 32 in Bangalore district and 8 to 25 in Kolar district) as the tomato cropping season advanced. But the level of resistance was high (168 - 249 folds) in Vadagur of Kolar district beyond September.

During kharif season spider mites showed low levels of resistance to propargite in both Bangalore (4-12 folds) and Kolar districts (6 to 11 folds). But the resistance increased further to moderate levels in the following months of December (2007) and February (2008).

At all the locations *T. urticae* populations from tomato exhibited their ability to tolerate the recommended toxic doses of all the acaricides tested especially in the later part of the cropping season.

Field evaluation with newer acaricidal molecules against dicofol-resistant *T. urticae* population in Vadagur of Kolar district revealed better effectiveness with milbemectin (3.75 g a.i./ha), fenazaquin (125 g a.i./ha), propargite (570 g a.i./ha), chlorfenapyr (75 g a.i./ha) and fenpyroximate (30 g a.i./ha), which accounted for 70% reduction in the egg population of spider mite. Chlorfenapyr, fenazaquin and propargite were superior in bringing down the population of active stages by 75 to 91%. However, against mixed stage population, milbemectin and fenazaquin causing 82 - 83% reduction were significantly more effective followed by propargite, chlorfenapyr and fenazaquin causing 70 - 76% reduction. The effect of diafenthiuron (450 g a.i./ha), abamectin (6 g a.i./ha) and mineral oil 1% was moderate recording 61 - 66% reduction.

From the overall findings it is evident that the *T. urticae* population on tomato has high level of resistance to dicofol and low to moderate level of resistance to newer acaricides. Application of newer molecules like, milbemectin (3.75 g a.i./ha), fenazaquin (125 g a.i./ha), propargite (570 g a.i./ha), chlorfenapyr (75 g a.i./ha) and fenpyroximate (30 g a.i./ha) in rotation at biweekly intervals would be appropriate for more effective control of the two spotted spider mite on tomato.

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** Original not seen*