INSECTICIDE MIXTURES FOR THE MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI

by

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(2017-11-025)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"INSECTICIDE MIXTURES FOR THE MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"INSECTICIDE MIXTURES FOR THE MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI"** is a record of research work done independently by Ms. Anju Viswanathan K under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDIX

LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
@	At the rate of
ADI	Acceptable daily intake
a.i	Active ingredient
bw d^{-1}	Body weight per day
CIB & RC	Central Insecticide Board and Registration Committee
CD	Critical Difference
CS	Contact and Stomach poison
DAS	Days after spraying
EC	Emulsifiable concentrate
et al	And others
FAO	Food and Agriculture Organization
g	Gram
GC- MS	Gas Chromatograph- Mass Spectrometry
ha^{-1}	Per hectare
HPLC	High Performance Liquid Chromatography
IRAC	Insecticide Resistance Action Committee
KAU	Kerala Agricultural University
kg	Kilogram
L	Litre

LC- MS	Liquid Chromatography- Mass spectroscopy
LOQ	Limit of quantification
mg	Milligram
ml	Millilitre
MPI	Maximum Permissible Intake
OD	Oil Dispersion
QuEChERS	Quick, Easy, Cheap, Effective, Rugged and Safe
RBD	Randomized Block Design
RSD	Relative Standard Deviation
SC	Suspension Concentrate
SD	Standard Deviation
SL	Soluble Liquid
sp	Species
TMRC	Theoretical Maximum Residue Concentration
viz.,	Namely
WG	Wettable Granules
WHO	World Health Organization
ZC	Zeon Capsules

Introduction

1. INTRODUCTION

Indian agricultural products continue to face rejections and bans in international markets due to non-compliance with food safety and health standards. Such non-compliance is because of several reasons including pest infestations, presence of insecticide residues higher than maximum approved levels, microbial contamination *etc.* Red chillies are one among the commodities facing threat for export due to rejections. In the mid-nineties, Indian dry chilli exports faced several rejections including rejections in Spain due to insecticide residue in excess of permissible maximum residue limits and in the US due to residues of quinalphos, an insecticide not registered in USA.

Chilli, *Capsicum annuum* L. is one of the important solanaceous crops and is widely cultivated throughout the world, especially in tropical and subtropical regions. Among the different constraints that lower productivity, the pest complex that attack chilli at different crop stages is the most important. The major pests that attack chilli are sucking pest complex *viz*., mites, *Polyphagotarsonemus latus* Banks, thrips, *Scirtothrips dorsalis* Hood, aphids, *Myzus persicae* Sulzer and *Aphis gossypii* Glove. One of the farmer's practice to reduce the pest infestation is the intermittent application of insecticides, which ultimately results in the huge deposition of insecticide residues on the crop and environment as well. The "Safe to eat project" operating in Pesticide Residue Research and Analytical Laboratory, College of Agriculture, Vellayani reported that 47.22 per cent of green chilli contains residues of an average of four to five different insecticides per sample (PAMSTEV, 2018).

Recently, different pesticide firms have commercialised various insecticide mixtures which can take care of sucking pests *viz,* mite, thrips, aphids, whiteflies as well as leaf feeders and chewing pests. Insecticide mixtures involve combinations of two or more insecticides having different mode of action into a single spray solution which entails exposing individual in an arthropod pest population to each insecticide simultaneously (Tabashnik, 1989; Hoy, 1998). Mixing insecticides with different modes of action may mitigate resistance development within insects because the mechanisms required to resist each insecticide in the mixture may not exist in insect population. That's how an insecticide mixture delay resistance. Besides it controls more than one pest at time with a single application, thereby saves energy, time and labour. Moreover the dose requirement for an insecticide mixture is as lower as compared to its individual insecticides (Das, 2014).

Several works indicated that insecticide mixtures are having enhanced efficacy for the control of chilli thrips (Nandhihalli, 2009), aphids, jassids and thrips in chilli (Sangamithra *et al.,* 2018). A study performed by Reddy (2018) in Kerala, revealed that chlorantraniliprole 8.8 % + thiamethoxam 17.5 % SC @ 150 g a.i ha^{-1} was effective in managing the population of pod bugs followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 27.5 g a.i ha^{-1} in cowpea. The literature available for the control of chilli pest complex by using insecticide mixtures is scanty under Kerala conditions. The studies regarding the dissipation of pesticide residues will help to gather information regarding the safety of products for human consumption. In this background, this present study, "Insecticide mixtures for the management of sucking pest complex in chilli" was undertaken with the following objectives,

- To evaluate the efficacy of insecticide mixture against sucking pest complex in chilli
- To quantify the amount of residues and its dissipation rate in chilli
- To assess the risk associated with the insecticide mixtures while human consumption.

Review of Literature

2. REVIEW OF LITERATURE

Chilli, *Capsicum annuum* L. is an important spice cum vegetable crop and a rich source of vitamin A, B, C and capsaicin. The largest producer of chilli in the world is India but the productivity is only 1.93 T ha^{-1} (Geetha and Selvarani, 2017) which has to be increased to a bench mark level of 5 T ha^{-1} to compete with the international market.

Among the different constraints that lower productivity, the pest complex that attack chilli at different crop stages is the most important factor. The main pests that attack the chilli are the mites, *P. latus*, thrips, *S. dorsalis,* aphids, *M. persicae and A. gossypii.* The yield loss due to chilli thrips and mites are estimated and reported to the tune of 50 per cent (Ahmed *et al*., 1987; Kandasamy *et al.,* 1990). In order to mitigate various pests of different feeding habits, farmers resort to individual application of different groups of insecticides and/ or acaricides with short spells, leads to deposition of huge amount of pesticide loads in crop as well as environment. This is evident from the frequent occurrence of insecticide residues in green chilli, higher mortality of beneficial arthropod fauna in chilli ecosystem. Insecticide mixtures, is one of the promising tool, which can take care of sucking pests *viz,* mite, thrips, aphids and whiteflies. However, the studies regarding the bio efficacy of insecticide mixtures against sucking pest complex in chilli under Kerala conditions are meagre.

2.1 SUCKING PESTS OF CHILLI

2.1.1 Solanum Whitefly, *Aleurothrixus trachoides* Back

The neotropical solanum whitefly, *A. trachoides* is found to be invasive in India. It is presently spreading fast in south India infesting many economically important plants of the family solanaceae like brinjal, chilli and tomato, hence it got the name 'solanum whitefly'. The agricultural economy in India is vulnerable to the emerging threat by invasion of the solanum whitefly in brinjal, chilli, tomato which are important solanaceous vegetables grown in our country. In India, so far it is found breeding on 24 host plants representing 11 families and observed in

Karnataka, Kerala, Maharashtra and Tamil Nadu. The economic loss is due to their activities of sucking the plant sap, acting as vectors of viral diseases and in production of honey dew leading to the development of sooty mould on leaves, thus adversely affecting photosynthesis. Heavy infestations caused chlorotic spots and curling of leaves resulting in their premature shedding and in severe infestation mortality of seedlings of chilli and tomato was observed (Sundararaj *et al.,* 2018).

2.1.2 Chilli Thrips, *S. dorsalis*

Thrips, *S. dorsalis* is a major sucking pest, infesting chilli right from germination to harvest and is responsible for low productivity, reduce up to 50 per cent yield (Ahmed *et al.,* 1987). According to Sanap and Nawale (1987), adult and nymphs of *S. dorsalis* suck the cell sap from leaves, causing rolling of the leaf upward and reduction of leaf size. Both adults and nymphs feed by rasping and sucking the oozing cell sap from the ventral side of the leaf, growing shoots, developing flowers and fruits leading to necrosis. Infested fruits develop corky tissues (Seal *et al.*, 2006). The affected leaves curl and exhibit characteristic symptom (Samota *et al.*, 2017). A severe infestation of chilli thrips makes the tender leaves and buds brittle, resulting in complete defoliation and total crop loss.

2.1.3 Chilli Mite, *P. latus*

The yellow mite, *P. latus* (Tarsonemidae) is one of the very important arthropod pests causing leaf curl in chilli throughout the globe. Damage by this mite is usually found to be heavier on the upper part of the plant than the middle and lower parts. The most conspicuous symptoms caused by *P. latus* on chilli include inward rolling of leaves in an inverted boat shape manner and has shiny, silvery lining on their ventral surface, rat tailing of leaf petiole, brittleness of foliage, aborted buds, distorted flowers, shoots grow twisted and fruits may be misshapen (Singh and Singh, 2013). The mite's toxic saliva causes twisted, hardened and distorted growth in the terminal part of the plant (Shukla, 2015).

2.1.4 Chilli Aphid, *A. gossypii*

The cotton aphid, *A. gossypii* and the green peach aphid, *M. persicae* are found infesting chillies. The adults are small, ovate, soft , greenish brown and sluggish in nature. Both nymphs and adults are found in large colonies on the under surface of leaves and growing shoots of plants, sucking the cell sap. The aphids also secrete honey dew on which black sooty mould develops covering the leaves and twigs. This black coating hinders the photosynthetic activity of the plant causing further retardation in growth and fruiting capacity of the plant (Butani, 1976). Infested plants turn pale, leaves become distorted, curled and crinkled leading to stunted growth of the plants (Kaur *et al.,* 2015).

2.2 EFFICACY OF INSECTICIDE MIXTURES IN CHILLI

Insecticide mixtures involve combinations of two or more insecticides having different mode of action into a single spray solution which entails exposing individual in an arthropod pest population to each insecticide simultaneously (Tabashnik, 1989; Hoy, 1998). Mixing insecticides with different modes of action may mitigate resistance development. Pests that are resistant to one or more insecticides may be susceptible to a combination of toxicants and synergism may be exhibited by the components. Insecticide mixtures are more effective to certain life stages of insects like egg, larvae, nymphs and adults than individual applications. Mixtures have promising options that has potential to increase the commercial lives of insecticides through their use in combinations, lowering their selection pressure, widening the spectrum of activity, simultaneously control two pest species, overcoming pest resistance to individual insecticide (Mosinski, 1998). Recently, different pesticide firms have commercialised various insecticide mixtures with different trade name, which can take care of sucking pests and Central Insecticide Board and Registration Committee (CIB & RC, 2018) itself recommending certain insecticide mixtures for major pests of chilli and other solanaceous vegetables (Table 1). Insecticide mixtures will continue to be an integral component of pest management programs due to the continual need to deal with a multitude of arthropod pests associated with agricultural cropping systems.

Table. 1- Insecticide mixtures recommended by CIB & RC for chilli and other solanaceous crops

SI No.	Insecticide mixture	Dosage (g a.i ha^{-1})	Recommended crop	Recommended pest
1	Cypermethrin 3% + Quinalphos 20% EC	50 + 50	Brinjal	Shoot and fruit borer
2	Beta cyfluthrin 8.49% + Imidacloprid 19.81% OD	15.75+36.75 – 18 + 42	Brinjal	Aphids, jassids, shoot and fruit borer
3	Chlorantraniliprole 8.8% w/w + Thiamethoxam 17.5 % w/w SC	500	Tomato	Leaf miner, whitefly and fruit borer
4	Deltamethrin 1% + Trizophos 35% EC	10+350- 12.5+450	Brinjal	Shoot and fruit borer, jassids, and epilachna beetle
5	Emamectin Benzoate 1.5% + Fipronil 3.5% SC	(7.50+17.50) - (11.25+26.25)	Chilli	Thrips and fruit borer
6	Flubendiamide 19.92% w/w+ Thiacloprid 19.92% w/w	48+48-60+60	Chilli	Thrips and fruit borer
7	Indoxacarb 14.5% + Acetamiprid 7.7% w/w SC	88.8-111	Chillies	Thrips and fruit borer
8	Novaluron 5.25% + Indoxacarb 4.5% SC	43.31 + 37.13 - 45.94 + 39.38	Tomato	Fruit borer and leaf eating caterpillar

9	Pyriproxyfen 5% EC + Fenpropathrin 15% EC	25+75 – 37.5 +112.5	Brinjal	Whitefly, shoot and fruit borer
10	Pyriproxyfen 5% EC + Fenpropathrin 15% EC	25+75 – 37.5 +112.5	Chilli	Whitefly and fruit borer
11	Spirotetramat 11.01% w/w + Imidacloprid 11.01% w/w SC	60 + 60	Brinjal	Whitefly and red spider mites
12	Thiamethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	33	Chilli	Thrips and fruit borer
13	Thiamethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	33	Tomato	Thrips, whiteflies and fruit borer

Dharne and Kabre (2009) conducted field experiments to test the bio-efficacy of a ready mixture of indoxacarb 14.5 + acetamiprid 7.7 % SC (RIL042 222 SC) against sucking pests and fruit borer on chilli. The treatments RIL042 222 SC @ 500 ml ha^{-1} and RIL-042 222 SC @ 400 ml ha^{-1} were significantly superior in reducing the incidence of sucking pests and fruit damage by *Helicoverpa armigera* Hubner. The treatment RIL-042 @ 500 ml ha^{-1} showed the highest green chilli fruit yield of 49.53 q ha^{-1}.

Nandihalli (2009) conducted an experiment on the efficacy of newer insecticide molecules against chilli thrips and fruit borer at the Agricultural Research Station, Dharwad during 2005 and 2006. Among different newer molecules, the combination insecticide indoxacarb 14.5 SC + acetamiprid 7.7% SC @ 500 ml ha^{-1} recorded less fruit borer damage with higher green fruit yield than indoxacarb 14.5 SC @ 500 ml ha^{-1} and acetamiprid 20 SP @ 200 g ha^{-1}.

Solomon 300 OD (Imidacloprid+ Beta cyfluthrin) was evaluated for its bioefficacy against insect pests of chilli at University of Agricultural Sciences, Dharward during 2015 and 2016. It was found that the combi product @ 310 ml ha^{-1} was superior in reducing thrips (0.62 six $leaves^{-1}$) and whiteflies (0.26 six $leaves^{-1}$) as compared to dimethoate 30 EC (1.35 and 1.74 six $leaves^{-1}$ respectively). The leaf curl index (LCI) was lower (0.90) in Solomon treated crop and 2.05 in dimethoate treatments in 0 to 4 scale. The lowest infestation of gall midge fly and *H. armigera* was observed in imidacloprid 27.9 + beta cyfluthrin 65.1 g a.i ha^{-1}@ 310 ml ha^{-1}. A significant high yield of 5.275 T ha^{-1} was obtained from Solomon treated plot @ 310 mL ha^{-1} followed by the same product at 240 ml ha^{-1} (Giraddi *et al.*, 2017).

2.3 EFFICACY OF INSECTICIDE MIXTURES AGAINST DIFFERENT CROP PESTS

All *et al.* (1977) reported that the mixtures of permethrin and chlorpyriphios showed increased toxicity against corn ear worm, *Heliothis zea* (Boddie), and the tobacco bud worm, *H. virescens.* Studies have demonstrated that insecticide mixtures increase the efficacy against insect pests such as whiteflies (Brownbridge *et al.,* 2000) and western flower thrips, *Frankliniella occidentalis* Pergande (Cloyd, 2003) compared to separate applications of each insecticide. Improved control of the two spotted spider mite was obtained with a mixture of the miticides fenpyroximate (pyrazole) and propargite (organosulfur) compared to miticides applied as single (Herron *et al.,* 2003).

It has been proposed that insecticide mixtures may delay the onset of resistance development in arthropod pest populations (Skylakakis, 1981; Mani, 1985; Mallet, 1989; Bielza *et al.,* 2009). Crowder *et al.* (1984) reported that a mixture of chlordimeform (formamidine) with permethrin, delayed resistance development in populations of the tobacco budworm.

Sanap and Patil (1998) reported that the combination insecticides *viz.,* Polytrin C- 44% EC (Profenofos 40% + Cypermethrin 4%) and Spark 36 EC (Triazophos 35% + Deltamethrin 1%) was superior in controlling pigeonpea pod borer compared to quinalphos 20 AF, methomyl 40 SP, profenofos 50 EC and chlorpyriphos 20 EC.

Sarangdevot and Kumar (2006) evaluated the efficacy of profenophos 50 EC (400 and 600 g a.i. ha^{-1}), Roket 44 EC (Cypermethrin 4 % EC + Profenophos 40% EC) at 400 and 600 g a.i ha^{-1} and cypermethrin 25 EC (40 g a.i ha^{-1}) against tomato fruit borer and Roket 44 EC at 600 g a.i ha^{-1} was found to be effective against fruit borer.

Kumar and Shivaraju (2009) studied the new insecticide molecules against tomato fruit borer, *H. armigera* and revealed that beta cyfluthrin 9 % + imidacloprid 21 % 300 OD @ 18 + 42 g a.i ha^{-1} was found to be very effective in suppressing the larval population to 75.95 per cent compared to monocrotophos 36 SL @ 450 g a.i ha^{-1} (68.67 %), beta cyfluthrin 2.5 SC @ 18 g a.i ha^{-1} (68.64 %), imidacloprid 200 SL @ 42 g a.i ha^{-1} (62.86 %) and triazophos 40 EC @ 400 g a.i ha^{-1} (58.23 %).

According to Mallapur *et al.* (2012) the insecticide mixture indoxacarb 14.5 SC + acetamiprid 7.7 SC @ 300 g a.i ha^{-1} was found as more effective against the pests of okra. It caused significant reduction in fruit borer damage during kharif and rabi season (9.11 and 19.10% respectively). Whereas, in the untreated treatment, the fruit damage was as high as 31.25 and 37.88 per cent during kharif and rabi season respectively.

Baskaran *et al.* (2012) studied the bio-efficacy of Alika 22.1 ZC (Thiamethoxam 12.6% + Lambda cyhalothrin 9.5%) against pest complex in groundnut. They reported that the application of Alika 22.1 ZC @ 150 and 125 ml ha^{-1} were effective in reducing the population of red hairy caterpillar and leaf miner. The insecticide mixture also recorded the highest pod yield at both doses.

Kumar and Chatterjee (2012) assessed the efficacy of new ready mixed insecticide, Plethora (novaluron 5.25 % + indoxacarb 4.5 % SC) at different concentrations in comparison with novaluron, indoxacarb and lambda cyhalothrin against insect pests of tomato and observed that new ready mixed insecticide Plethora @ 825 ml ha^{-1} was effective in reducing the larval population of *H. armigera* up to 100 per cent within three days after third application that ultimately increased the yield of tomato.

Ghosal *et al.* (2016) also conducted experiments to test the effectiveness of ready mix insecticide Plethora (Novaluron 5.25 % + Indoxacarb 4.5 % SC) along with other insecticides against *H. armigera* and *S. litura* infesting tomato during rabi season 2009 and 2010. They reported that the Plethora @ 875 mL ha^{-1} recorded only 3.75 per cent fruit damage, while in control plot it was 45.6 per cent. They also conducted field experiments with different schedules of novaluron 5.25% + indoxacarb 4.5% SC against pod borer of pigeon pea. Among the three selected dose of (750, 825, 875 ml ha^{-1}) novaluron 5.25 % + indoxacarb 4.5% SC, 875 ml ha^{-1} was recorded as the best in managing *H. armigera* population.

Thangavel *et al.* (2014) studied bioefficacy of Alika 247 ZC (Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 %) on tomato fruit borer and revealed that three round application of Alika 247 ZC @ 150 ml ha^{-1} at ten days interval starting from 45 days after transplanting recorded the lowest mean population of *H. armigera* (1.00 plant $^{-1}$) and fruit damage (2.36 %) which was on a par with Alika 247 ZC @ 125 ml ha^{-1} (1.37plant $^{-1}$ and 3.21 %) followed by Alika 247 ZC @ 100 ml ha^{-1} (1.70 plant $^{-1}$ and 4.08 %).

Bajya *et al.* (2015) evaluated the efficacy of Ampligo 150 ZC (Chlorantranilipole 9.3 % + Lambda cyhalothrin 4.6 % ZC) in cotton and found that Ampligo 150 ZC at 37.5, 45 and 60 g a.i ha^{-1} was highly effective in checking the larval population of *Earias* spp., *H. armigera, Pectinophora gossypiella* Saunders and *Spodoptera litura* Fabricius as compared to standard check such as chlorantranilipole 18.5 SC @ 30 g a.i ha^{-1}, qunalphos 25 EC @ 500 g a.i ha^{-1}, deltamethrin 2.8 EC @ 12.5 g a.i ha^{-1} and lambda cyhalothrin 4.9 CS @ 25 g a.i ha^{-1}.

Another study was conducted in Kerala Agricultural University, in order to evaluate the efficacy of insecticide mixtures against pests of cowpea during 2016 to 2018. This study revealed that, chlorantraniliprole 8.8 % + thiamethoxam 17.5 % SC @ 150 g a.i ha^{-1} was effective for managing the population of pod bug, *Riptortus pedestris* Fabricius, followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 27.5 g a.i ha^{-1} and beta cyfluthrin 8.49 % + imidacloprid 19.81 % SC @ 15.75 + 36.7 g a.i ha^{-1}. No aphids, *Aphis craccivora* Koch were observed in treatments *viz.,* chlorantraniliprole 8.8 % + thiamethoxam 17.5 % SC @ 150 g a.i ha^{-1} and thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 27.5 g a.i ha^{-1} as it was high in untreated control (211.67 aphids plant^{-1}). Less incidence of larvae of *Maruca vitrata* Fabricius was found in plants treated with lambda cyhalothrin 4.6 % + chlorantraniliprole 9.3 % ZC @ 30 g a.i ha^{-1} and chlorantraniliprole 8.8 % + thiamethoxam 17.5 % SC @ 150 g a.i ha^{-1} as it was high in control plant (6.67 larvae pod^{-1}). The treatments chlorantraniliprole 8.8 % + thiamethoxam 17.5 % SC @ 150 g a.i ha^{-1}, thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 27.5 g a.i ha^{-1} and lambda cyhalothrin 4.6 % + chlorantraniliprole 9.3 % ZC @ 30 g a.i ha^{-1} were found to be the effective insecticide mixtures for controlling pest complex in cowpea (Reddy, 2018).

2.4 EFFICACY OF SINGLE INSECTICIDE AGAINST PESTS OF CHILLI

The pests of chilli can be managed by single insecticide. The advantage of insecticide mixtures over single insecticide is that, it can manage more than one pest with a single spray. The effectiveness of single insecticide against major pests of chilli is renewed in Table. 2.

2.5 SAFETY OF INSECTICIDES TOWARDS NATURAL ENEMIES

Natural enemies, especially predators, are known to regulate population of pest species in agro-ecosystems. The ecosystem of chilli is ravaged by a number of natural enemies like spiders, coccinellids, predatory mites, dragonflies *etc.*

Axinoscymus puttarudriahi Kapur and Munshi, is a coccinellid predator seen in whitefly colonies (Kapur and Munshi, 1965) and could control the population of nymphs and adults of whiteflies. Apart from this, *Cheilomenes sexmaculata* Fabricius, *Coccinella septumpunctata* Linneaus, spiders and syrphids are also observed in chilli ecosystems which mainly feeds on aphids, *A. gossypii.*

A field study was conducted to assess the relative toxicity of spiromesifen, fenpyroximate and thiocloprid on scale feeding and aphidophagous coccinellids in apple orchard of Kashmir. The mortality of both scale feeder as well as aphidophagous coccinellids increased with increased insecticidal concentration and time interval. Among all tested insecticides, fenpyroximate was found safer to both scale feeder and aphidophagous coccinellids (Khan, 2009). The spray of imidacloprid 350 SC at 100, 125 and 150 ml ha^{-1} did not cause significant adverse effect on the common natural enemies of chilli such as *Coccinella* spp. and *Chrysoperla* present in chilli eco-system (Rana *et al.,* 2016).

Seal *et al.* (2006) studied the compatibility of insecticides against natural enemies on pepper and found that spinosad was found to be slightly harmful while, chlorfenapyr was moderately harmful to *Cryptolaemus* sp. Ghosh *et al.* (2010) indicated that spinosad at 73 to 84 g a.i ha^{-1} was very safe to important predators of tomato.

Table. 2 Insecticides recommended against pests of chilli

SI No.	Insecticide	Concentration	Pest	Reference
1	Imidacloprid 200SL	3 ml l^{-1}	*Aphis gossypii*	Chiranjeevi *et al.* (2002)
2	Imidacloprid 70 WS	Seed treatment @ 20 and 30 g kg^{-1}	*Scirtothrips dorsalis, Bemisia tabaci* and *Aphis gossypii*	Santharam *et al.* (2003)
3	Imidacloprid 350 SC	52.5 g a.i ha^{-1}	*Scirtothrips dorsalis, Bemisia tabaci ,Aphis gossypii* and *Polyphagotarsonemus latus*	Jain and Ameta (2006)
4	Beta cyfluthrin 0.25 SC	75 ml ha^{-1}	*Scirtothrips dorsalis, Bemisia tabaci* and *Helicoverpa armigera*	Jain and Ameta (2006)
5	Thiamethoxam 25 WG	0.005 %	*Scirtothrips dorsalis*	Mandi and Senapati (2009)
6	Fipronil 80 WG	50 g a.i ha^{-1}	*Scirtothrips dorsalis*	Reddy *et al.* (2005)
7	Thiamethoxam	40 g a.i ha^{-1}	*Aphis gossypii*	Varghese and Mathew (2012)
8	Imidacloprid	17.8 g a.i ha^{-1}	*Aphis gossypii*	Varghese and Mathew (2012)
9	Spiromesifen 45 SC	100 g a.i ha^{-1}	*Polyphagotarsonemus latus*	Varghese and Mathew (2013)
10	Lambda cyhalothrin 4.9 CS	25 g a.i ha^{-1}	*Scirtothrips dorsalis*	Patra *et al.* (2015)

11	Thiamethoxam 25 WG	50 g a.i ha^{-1}	*Scirtothrips dorsalis*	Sujay *et al.* (2015)
12	Fipronil 5 SC	40 g a.i ha^{-1}	*Aphis gossypii* and *Scirtothrips dorsalis*	Rana *et al.* (2016)
13	Fipronil 200 SC	50 g a.i ha^{-1}	*Aphis gossypii*	Indhumathi *et al.* (2017 a)
14	Lambda cyhalothrin 5 EC	15 g a.i ha^{-1}	*Aphis gossypii*	Indhumathi *et al.* (2017 a)
15	Spiromesifen 22.9 SC	75 mL ha^{-1}	*Polyphagotarsonemus latus*	Pathipati *et al.* (2017)
16	Spiromesifen 240 SC	90 g a.i ha^{-1}	*Polyphagotarsonemus latus*	Samanta *et al.* (2017)
17	Fipronil 5 SC	0.01 %	*Scirtothrips dorsalis*	Samota *et al.* (2017)
18	Imidacloprid 17.8 SL	0.005 %	*Scirtothrips dorsalis*	Samota *et al.* (2017)

Spiromesifen was found to be the safest insecticide against natural enemies like predatory mites, coccinellid beetles, spiders and neutral insects whereas the organophosphate insecticide like dimethoate 30 EC 300 g a.i ha^{-1} was found to be unsafe to natural enemies in chilli ecosystem (Varghese and Mathew, 2013). Significant higher number of coccinellids was noticed in plants treated with spinosad 45 SC (1.14 $leaf^{-1}$) and emamectin benzoate 5 SG (1.08 $leaf^{-1}$) and it was found to be statistically on par with untreated check (1.17 $leaf^{-1}$). Similarly less number of *Chrysoperla* was noticed in profenophos 50 EC treated plots (0.62 $leaf^{-1}$) when compared to spinosad 45 SC (1.39 $leaf^{-1}$) and untreated control (1.81 $leaf^{-1}$) (Sujay *et al.,* 2015).

Lambda cyhalothrin 4.9 % CS was relatively safe to two important predators, *Menochilus* sp. and *Chrysoperla* sp. in comparison to fipronil 5% SC in chilli. The highest dose of lambda cyhalothrin (25 g a.i ha^{-1}) causes a reduction of 20.82 per cent in population of *Menochilus* sp. but it is lower than fipronil 5% SC (31.29 %). Spinosad was equally safe or in some cases safer than lambda cyhalothrin 4.9 % CS against the natural enemies (Patra *et al.,* 2015).

2.6 DISSIPATION, PERSISTENCE AND RISK ASSESSMENT OF INSECTICIDES IN CHILLI

Indian exports faced more border rejections compared to exports from countries such as Brazil, and the number of border rejections in proportion to the notifications is the highest for India between 2005 to 2017, this is mainly because of the presence of pesticide residues. The Kerala Agricultural University, has reported that, about 86 per cent of chilli samples were contaminated with ethion during 2016 in a survey conducted in Thiruvanthapuram district (PAMSTEV, 2018).

Dissipation pattern of different insecticides may vary in various crops with different half-lives. The dissipation pattern of lambda cyhalothrin 5% SC @ 15.63 g a.i ha^{-1} was studied in chilli by collecting samples at regular intervals at 0, 1, 3, 5, 7, 10 and 15days after last spray. The initial deposits of 1.20 mg kg^{-1} of lambda cyhalothrin recorded at 2 h after last spray and dissipated to 0.78, 0.36 and 0.09 mg kg^{-1} at 1, 3 and 5 days after last spray respectively and below limit of quantification (LOQ) by 7th day (Reddy *et al.,* 2017).

A study conducted by Pathipati (2017) in chilli concluded that, an initial deposits of 1.29 mg kg^{-1} of spiromesifen was detected at 2 h after spray, dissipated to 0.62, 0.16 and 0.05 mg kg^{-1} by 1, 3 and 5 days after spray, respectively under open field conditions. The residues reached LOQ at 7th day after spray. The dissipation pattern showed decrease of residues from first day to 7th day and residues dissipated by 51.93, 87.59, 96.12 and 100.00 per cent at 1, 3, 5 and 7 days respectively.

Sahoo *et al.* (2009) have reported that average initial deposit of flubendiamide in chilli were 1.06 and 2.00 mg kg^{-1}, which dissipated to below detectable level of 0.01 mg kg^{-1} in 7 and 10 days at 60 and 120 g a.i ha^{-1} dosages, respectively. Kooner *et al.* (2010) studied the dissipation pattern of flubendiamide and thiacloprid on tomato and reported that, an average initial deposits of 0.08 and 0.16 mg kg^{-1}, respectively, which dissipated to below LOQ in 3 and 5 days at lower (48 g a.i. ha^{-1}) and higher (96 g a.i ha^{-1}) dosages, respectively.

Study conducted by Kumar *et al.* (2018) revealed that, thiacloprid 240 SC @ 63 g a.i ha^{-1} resulted in an initial residue deposit of 0.128 mg kg^{-1}. The dissipation pattern was in first order kinetics with residues of 0.097, 0.071, 0.050 and 0.021 mg kg^{-1} on 3, 5, 7 and 10 days after spraying. The residues reached LOQ of 0.01 mg kg^{-1}on 15th day after spraying.

In Kerala, Mathew *et al.* (2012) conducted a dissipation study of a combination insecticide spirotetramat + imidacloprid 240 SC @ 120 +120 g a.i ha^{-1} on chilli. The initial deposit was found as 1.2 and 2.53 mg kg^{-1} for spirotetramat and imidacloprid respectively. The residues reached LOQ of 0.05 mg kg^{-1} on 15th day after spraying for spirotetramat and 35th day after spraying for imidacloprid.

Parmar *et al.* (2012) studied the dissipation pattern of a combination insecticide of flubendiamide + thiacloprid @ 60 + 60 g a.i ha^{-1} on chilli. The initial deposit was found as 0.24 and 0.16 mg kg^{-1} for flubendiamide and thiacloprid respectively. The days to reach LOQ of 0.05 mg kg^{-1} flubendiamide and thiacloprid respectively was found as 3 and 5 for flubendiamide and thiacloprid respectively.

Sanyal *et al.* (2008) studied the risk assessment of chilli by comparing TMRC and it was found that MPI was higher than TMRC and consumption of acetamiprid treated chilli was safer. Bhattacharyya *et al.* (2017) studied the risk assessment of emamectin benzoate + fipronil 3.5 % EC and reported that, the insecticide was safe for consumption at the recommended doses in chilli. Thiacloprid applied at the lower (63 g a.i ha^{-1}) and higher (126 g a.i ha^{-1}) doses to chilli pepper did not pose any risk to humans, even on the day of application (Kumar *et al.,* 2018).

Materials and Methods

3. MATERIALS AND METHODS

Laboratory and field experiments were conducted to evaluate the efficacy of insecticide mixtures in managing sucking pest complex in chilli. Laboratory evaluation was conducted at Department of Agricultural Entomology and estimation of residues of these insecticide mixtures were carried out at Pesticide Residue Research and Analytical Laboratory, College of Agriculture, Vellayani. The field trial was conducted in the farmer's field at Kalliyoor Panchayath, Thiruvanathapuram. Safety evalution of these insecticide mixture towards natural enemies, *viz.*, spiders and coccinellids were also carried out under field condition. The materials used and the methods adopted are detailed here under.

3.1 PRELIMINARY EVALUATION OF INSECTICIDE MIXTURES AGAINST SUCKING PEST COMPLEX IN CHILLI

Seven insecticides (five insecticide mixtures and two single insecticides) (Table. 3) were evaluated against the following pests of chilli. The experiment was laid out in completely randomized block design (CRD) with three replications and an untreated control.

The sucking pests in chilli selected for the study were,

1. Whiteflies - *Aleurothrixus trachoides* (Back)
2. Chilli thrips - *Scirtothrips dorsalis* (Hood)
3. Chilli mite - *Polyphagotarsonemus latus* (Banks)
4. Aphids - *Aphis gossypii* (Glover)

3.1.1 Raising of Plants for Preliminary Evaluation of Insecticide Mixtures

The plants were raised with seedlings of chilli (variety Vellayani Athulya) procured from the Department of Vegetable Science, College of Agriculture, Vellayani. Two weeks old seedlings were transplanted into the plastic pots (10.00 cm diameter) and placed at Department of Agricultural Entomology, College of Agriculture, Vellayani during September 2018 (Plate.1). The test plants were maintained for the natural infestation of sucking pests.

Plate 1. Preliminary evaluation of insecticide mixtures

3.1.2 Evaluation of Insecticide Mixtures

The crops were sprayed with the insecticide mixtures and single insecticide at the recommended doses when ten per cent infestation of all pests were noticed on the test plants, which were maintained in the pots for natural infestation of sucking pest complex. No second spray was given since there was no recurrence of sucking pest complex. The details of the treatments are presented in Table. 3.

3.1.3 Evaluation Against Sucking Pest Complex in Chilli

3.1.3.1 Whiteflies, A. trachoides

Potted plants infested with whiteflies, *A. trachoides* were selected for the evaluation. The number of adult whiteflies were counted one day before spraying (precount) and 1, 3, 5, 7, 10 and 15 DAS (whitefly count were taken during morning hours as they were not active at morning and evening hours). Six leaves, two each from top, middle and bottom of plant were closely observed for whiteflies, *A. trachoides*. Mean number of whiteflies present in each leaf was calculated.

3.1.3.2 Chilli Thrips, S. dorsalis

Potted plants infested by chilli thrips, *S. dorsalis* were selected for the evaluation. The thrips count were taken one day before spraying (pre count) and 1, 3, 5, 7, 10 and 15 DAS. Six leaves, two each from top, middle and bottom of plant were closely observed for chilli thrips, *S. dorsalis* and counted them by using hand lens (Varghese, 2011). Mean number of thrips present in leaf was calculated.

3.1.3.3 Chilli Mite, P. latus

Potted plants infested by chilli mite, *P. latus* were selected for evaluation. The mite counts were taken one day before spraying (pre count) and 1, 3, 5, 7, 10 and 15 DAS (Varghese, 2011).

Six leaves, two each from top, middle and bottom of plant were closely observed for chilli mite, *P. latus* and counted them by using hand lens. Mean number of mites present in each leaf was calculated.

Table 3. Details of insecticide mixtures/ insecticides used for the management of sucking pest complex in chilli

SI. No.	Details of insecticide mixtures/ insecticide				
	Chemical name	Trade name	Chemical group	Mode of action as per IRAC	Dosage (g a.i ha^{-1})
1	Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 % ZC	Alika	Neonicotinoid + Synthetic pyrethroid	Nicotinic acetylcholine receptor competitive modulators+ Sodium channel modulators	33 + 15.75
2	Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD	Solomon	Synthetic pyrethroid + Neonicotinoid	Sodium channel modulators + Nicotinic acetylcholine receptor competitive modulators	15.75 +36.75
3	Flubendiamide 19.92% + Thiacloprid 19.92 % SC	Belt expert	Diamide + Neonicotinoid	Ryanodine receptor modulators + Nicotinic acetylcholine receptor competitive modulators	48 + 48
4	Fipronil 40% + Imidacloprid 40% WG	Fipromida	Phenyl pyrazole + Neonicotinoid	GABA gated chloride channel bolckers + Nicotinic acetylcholine receptor competitive modulators	175 + 175

5	Hand mixing of Spiromesifen 22.9% SC + Thiamethoxam 25 % WG (1:1)	Oberon + Actara	Tetronic acid derivatives + Neonicotinoid	Inhibitors of acetyl co enzyme A carboxylase + Nicotinic acetylcholine receptor competitive modulators	-
6	Spiromesifen 22.9% SC (positive control 1)	Oberon	Tetronic and tetramic acid derivatives	Inhibitors of acetyl co enzyme A carboxylase	96
7	Thiamethoxam 25 % WG (positive control 2)	Actara	Neonicotinoid	Nicotinic acetylcholine receptor competitive modulators	50

3.1.3.2 Aphids, A. gossypii

Potted plants infested with aphids, *A. gossypii* were selected for the evaluation. The aphids count were taken one day before spraying and 1, 3, 5, 7, 10 and 15 DAS. The number of aphids were taken from 6 leaves, three each from top and middle (Kumar *et al.,* 2010). Mean number of aphids present in each leaf was calculated.

3.2 FIELD EVALUATION OF SELECTED INSECTICIDE MIXTURES AGAINST SUCKING PEST COMPLEX IN CHILLI.

Four effective insecticides (two insecticide mixtures and two single insecticide) from the seven new generation insecticides (five insecticide mixtures and two single insecticide) tested in the laboratory condition against sucking pest complex in chilli, were selected along with untreated control for conducting field experiment.

The field experiment was conducted at Nilama, Ookkodu in the farmer's field at Kalliyoor Panchayath of Thiruvanathapuram district during September 2018 to December 2018 (Plate.2). The crops were raised as per the recommendations given in the Package of Practices of Kerala Agricultural University (KAU, 2016).

Design - RBD

Treatments - 5

Replications - 4

Variety - Vellayani Athulya

The insecticides selected for the management of sucking pest complex in chilli in field experiment is given in Table. 4.

The insecticide mixtures/ insecticides were sprayed at their recommended doses in chilli when ten per cent infestation of pests (Plate. 3) were observed. No

Plate 2. General view of field, Kalliyoor

Chilli mite, *Polyphagotarsonemus latus*

Chilli thrips, *Scirtothrips dorsalis*

Chilli aphid, *Aphis gossypii*

Fruit borer, *Spodoptera litura*

Whitefly, *Aleurothrux trachoides*

Plate 3. Common pests of chilli

Table. 4 Details of insecticide mixture/ insecticide selected for field evaluation against pest complex in chilli

SI. No.	Details of insecticide mixtures/ insecticide				
	Chemical name	Trade name	Chemical group	Mode of action as per IRAC	Dosage (g a.i ha^{-1})
1	Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD	Solomon	Synthetic pyrethroid + Neonicotinoid	Sodium channel modulators + Nicotinic acetylcholine receptor competitive modulators	15.75 +36.75
2	Fipronil 40% + Imidacloprid 40% WG	Fipromida	Phenyl pyrazole + Neonicotinoid	GABA gated chloride channel bolckers + Nicotinic acetylcholine receptor competitive modulators	175 + 175
3	Spiromesifen 22.9% SC	Oberon	Tetronic acid derivatives	Inhibitors of acetyl co enzyme A carboxylase	96
4	Thiamethoxam 25 % WG	Actara	Neonicotinoid	Nicotinic acetylcholine receptor competitive modulators	50

second spray was given since there was no recurrence of pest complex. The procedure for counting whiteflies, chilli thrips, chilli mites and aphids is explained in experiment 3.1.3.

3.2.5 Leaf Curl Index (LCI)

In order to identify the extent of damage caused by chilli mite and thrips, LCI was calculated. The intensity of leaf curl was assessed visually by looking in to the standard scoring procedure (Kumar *et al.,* 1996) mentioned below.

Table. 5. Score chart for the calculation of Leaf curl index

Score	Symptom
0	No symptom
1	1 to 25% leaves/ plant show curling
2	26 to 50% leaves/ plant show curling
3	51 to 75% leaves/ plant show curling, heavily damaged, malformation of growing points and reduction in plant height.
4	More than 75% leaves/ plant show curling, severe and complete destruction of growing points, drastic reduction in plant height, defoliation and severe malformation

Ten plants were selected randomly in each plot and scored for leaf curling visually (Plate. 4) by following the standard scoring procedure mentioned in the Table 4, before insecticidal spraying and 15, 30 and 45 DAS.

Score '0'

Score '1'

Score '2'

Score '3'

Score '4'

Plate. 4 Scoring of plants for leaf curl index calculation

$$LCI = \frac{(1 \text{ x number of plants under score '1'}) + (2 \text{ x number of plants under score '2'}) + (3 \text{ x number of plants under score '3'}) + (4 \text{ x number of plants under score '4'})}{\text{Total number of plants under observation}}$$

3.3 SAFETY EVALUATION OF INSECTICIDE MIXTURES AGAINST SPIDERS AND COCCINELLIDS

The plants randomly selected for the bio efficacy studies of insecticide mixtures/ insecticides were observed for the population density of common predators seen in chilli ecosystem *viz.,* spiders and coccinellids (Plate. 5). The number of spiders and coccinellids seen in the plots were counted and mean value were calculated one day before spraying and 1, 3, 5, 7, 10 and 15 DAS.

3.4 PERSISTENCE AND DEGRADATION OF INSECTICIDE RESIDUES IN CHILLI.

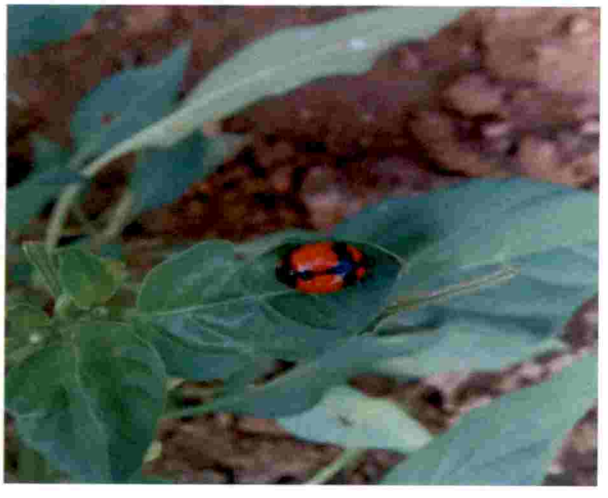
The studies on the persistence and degradation of the insecticide mixtures/ insecticides in chilli fruits were done in the Pesticide Residue Research and Analytical Laboratory (PRRAL), College of Agriculture (COA), Vellayani.

3.4.1 Method Validation Studies

Recovery experiments were carried out to assess the efficacy of extraction and clean up procedures adopted to standardize the procedure for pesticide residue estimation from chilli fruits. For conducting the experiment, chilli plants were raised without applying any of the insecticides. Fruits were harvested and homogenized at PRRAL, COA, Vellayani. Homogenized chilli fruits were separately spiked at different levels with the certified reference material (CRM) of the seven insecticides/ insecticides as described in Table. 6. The samples were extracted and cleaned up as per the procedures given below.

Axinoscymus puttarudriahi

Cheilomenes sexmaculata



Coccinella septumpunctata

Oxyopes sp.

Tetragnatha sp.

Plate. 5 Common coccinellids and spiders in chilli ecosystem

Table. 6 Details of certified reference (CRM) materials used for pesticide residue analysis

SI No	Name of the CRM	Purity of CRM (%)	Purchased from
1	Beta cyfluthrin	99.3	M/s Sigma-Aldrich (Steinheim, Germany)
2	Imidacloprid	99.9	M/s Sigma-Aldrich (Steinheim, Germany)
3	Lambda cyhalothrin	98.7	M/s Sigma-Aldrich (Steinheim, Germany)
4	Fipronil	99.4	M/s Sigma-Aldrich (Steinheim, Germany)
5	Flubendiamide	98.6	M/s Sigma-Aldrich (Steinheim, Germany)
6	Thiacloprid	99.9	M/s Sigma-Aldrich (Steinheim, Germany)
7	Thiamethoxam	99.3	M/s Sigma-Aldrich (Steinheim, Germany)
8	Spiromesifen	99.9	M/s Sigma-Aldrich (Steinheim, Germany)

3.4.1.1 Preparation of Standard Insecticides

CRM of pesticides *viz.,* beta cyfluthrin, imidacloprid, lambda cyhalothrin, fipronil, flubendiamide, thiacloprid, thiamethoxam and spiromesifen with 99.3, 99.9, 98.7, 99.4, 98.6, 99.9, 99.3 and 99.9 per cent purity respectively were procured from M/s Sigma Aldrich. Stock solutions 1000 μg ml^{-1} of the insecticides were prepared by dissolving a weighed quantity of the analytical grade material in HPLC grade methanol. The stock solutions were serially diluted to prepare an intermediate stock of 100 μg ml^{-1}. The intermediate stock solutions were further diluted with HPLC grade methanol to prepare working standard mixtures of each insecticides for residue quantification using LC- MS/MS by positive electro spray ionization (betacyfluthrin, imidacloprid, lambda cyhalothrin, fipronil, thiacloprid, thiamethoxam and spiromesifen) and by negative electro spray ionization (flubendiamide). The working standard mixtures were serially diluted to obtain 1.00, 0.50, 0.25, 0.10, 0.05, 0.01 and 0.005 μg ml^{-1} of analytical grade insecticides.

3.4.1.2 Fortification and Recovery Experiments

Chilli fruits (500 g) harvested from the plots with no pesticide application were cut and blended to a fine paste. Five replicates of 25 g representative samples of the fruits were taken in 50 ml centrifuge tubes and spiked with 0.05 (LOQ), 0.25 (2 x LOQ) and 0.50 (5x LOQ) ml of working standard mixtures of the insecticides. The extraction and clean- up were done by following QuEChERS method (Anastassiades *et al.,* 2003) and quantified by using LC MS/MS under optimized conditions. The method which gave recovery of insecticide in the range of 70 to 120 per cent with a relative standard deviation less than 20 was considered to be the ideal method.

3.4.2 Estimation of Persistence and Degradation of Residues

3.4.2.1 Sampling

Chilli fruits sprayed with insecticides mentioned in Table 3 were collected from the field at two hours, 1, 3, 5, 7, 10, 15 and 30 DAS, brought to Pesticide

Residue Research and Analytical Laboratory and processed immediately for residue analysis.

3.4.2.2 Extraction of Residues

The multiresidue estimation procedure recommended for vegetables as per QuEChERS method with suitable modification was adopted for extraction and clean- up of residues in chilli. The harvested fruits were blended in a high speed blender (BLIXER 6 vv Robot Coupe) and a representative sample of 25 g of chilli was taken in a 250 ml centrifuge bottle. HPLC grade acetonitrile (50 ml) was added to the samples and homogenized with a high speed tissue homogenizer (Heidolph Silent Crusher- M) at 1400 rpm for three minutes. This was followed by the addition of 10 g activated sodium chloride (NaCl) and vortexed for two minutes for the separation of acetonitrile layer. The samples were then centrifuged for 8 minutes at 2500 rpm and 16 ml of the clear upper layer was transferred into a 50 ml centrifuge tubes containing 6 g preactivated sodium sulphate and vortexed for 2 minutes. The acetonitrile extracts were subjected to clean up by dispersive solid phase extraction (DSPE). For this 12 ml of the upper layer was transferred into centrifuge tubes (15 ml) containing 0.20 g primary secondary amine (PSA) and 1.2 g of magnesium sulphate. The tubes were then centrifuged at 2500 rpm for 5 minutes. The supernatant liquid were transferred into turbovap tube (3 ml for LC compounds and 4 ml for GC compounds) and evaporated to dryness under a gentle steam of nitrogen using a Turbovap set at 40°C and 7.5 psi nitrogen flow. The residues were reconstituted in 1.5 ml of methanol for fipronil, flubendiamide, thiacloprid, imidacloprid, thiamethoxam spiromesifen (LC compounds) and in 1 ml n- hexane for beta cyfluthrin and lambda cyhalothrin (GC compounds), filtered through a 0.2 micron filter (PVDF) prior to estimation in LC- MS/MS respectively.

3.4.3 Instrumentation

3.4.3.1 LC- MS/MS

The chromatographic separation was achieved by using Waters Acquity UPLC system equipped with a reversed phase Atlantis d c- 18 (100x 2.1 mm, 5µm particle size) column. The moisture phase consists of gradient system involving the following eluent compounds *viz.,* (A) 10% methanol in water + 0.1% formic acid+ 5 mM ammonium acetate and (B) 10% water in methanol+ 0.1% formic acid+ 5 mM ammonium acetate was used as mobile phase for the separation of residues. The gradient elution was done as follows, 0 min isocratic 20% B, increased to 100% B in 9 min, decreased to the initial composition of 20% B in 10 min and hold to 12 min for re equilibration. The flow rate remains constant at 0.8 ml min^{-1} and injection volume was 10 µl. the column temperature was maintained at 40°C. The effluent from the LC system was introduced into triple quadrupole API 3200 MS/MS system equipped with an electro spray ionization interface (ESI), operating in the positive ion mode. The source parameters were temperature 600°C, ion gas (GSI) 50 psi, ion gas (GS2) 60 psi, ion spray voltage 5,500 V, curtain gas 13 psi.

3.4.3.2 GC- ECD

Estimation of residues of lambda cyhalothrin and beta cyfluthrin were performed using gas chromatograph (Shimadzu 2010 AT) equipped with Electron Capture Detector (ECD). Operating conditions of GC were, column, DB- 5 capillary (0.25µm film thickness x 0.25 mm x 30 mm), carrier gas- nitrogen, column flow- 0.79 ml/ min, injector temperature - 250°C and detector temperature used was 300°C. The residues of lambda cyhalothrin and beta cyfluthrin were confirmed in GC- MS (Shimadzu GC- MS QP 2010 Plus) with retention time of 50.25 min and 61.10 min respectively. Helium was used as carrier gas in GC- MS operated with Electron Impact Ionization (70 eV). In GC- MS injector temperature, column, column flow was similar to that of GC.

The LC-MS/MS or GC- MS/MS condition was optimized by using direct infusion into ESI source in positive mode to provide the highest signal/ noise ratio for the quantification of each analyte. Two MS/MS transitions were made in case of chemical interferences observed in the quantitation ion chromatogram and for qualitative purpose. The ion source temperature was 550°C with ion spray voltage of 5500 V. in each segment corresponding MS/MS transitions were monitored using multiple reactions – monitoring (MRM) mode.

3.4.4 Residue Quantification

Based on the peak area of the chromatogram obtained for various insecticides, the quantity of residue was determined as detailed below.

$$\text{Pesticide residue (mg kg}^{-1}\text{)} = \frac{\text{Volume of the solvent added x Final volume of extract (ml)}}{\text{Weight of sample x Volume of extract taken for concentration}}$$

The persistence of insecticides are generally expressed in terms of half- life (DT 50) *ie.,* time for disappearance of pesticide to 50 per cent of its initial concentration. To determine the half- life of insecticides, Hoskins (1961) equation is used.

3.5 RISK ASSESSMENT OF INSECTICIDE MIXTURES IN CHILLI

Theoretical Maximum Residue concentration (TMRC) was calculated by multiplying the maximum residue levels with average per capita daily consumption in Indian context. Safety parameters were evaluated by comparing the TMRC with Maximum Permissible Intake (MPI) (Bhattacharya *et al.,* 2017). If TMRC value is less than MPI, then the particular insecticide is said to cause no health impact.

TMRC = Maximum residue level obtained at recommended dose on 0^{th} day of application x total intake of food per day.

MPI = Acceptable daily intake (ADI) x average body weight (60 Kg) of an adult of human being.

The prescribed ADI values of insecticides were given by FAO/ WHO.

3.5 STATISTICAL ANALYSIS

Data on each experiment were analysed and appropriate methods of analysis were done (Panse and Sukhatme, 1967). Suitable transformation were applied and significant results were equated on the basis of critical differences.

Results

4. RESULTS

4.1 PRELIMINARY EVALUATION OF INSECTICIDE MIXTURES AGAINST SUCKING PEST COMPLEX IN CHILLI

The results on the effectiveness of insecticide mixtures against the major sucking pest complex in chilli *viz., A. trachoides , S. dorsalis, P. latus,* and *A. gossypii* when evaluated under laboratory conditions are presented in Table 6 to 9.

4.1.1 **Whitefly, *A. trachoides***

The effectiveness of insecticide mixtures was evaluated against the population of whiteflies, *A. trachoides* in chilli is shown in Table 7. The population of whiteflies was expressed as number leaf^{-1}.

The population of whiteflies before spraying was found to be uniform and thus it was non significant. On the first day after spraying, significantly lower population was recorded in fipronil 40 % + imidacloprid 40 % WG @175 + 175 g a.i ha^{-1} (1.88) followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.22), thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (2.44) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.77) and were significantly different also. Among all the treatments a higher population of whiteflies was observed in hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (3.33) after untreated control (5.11).

On the third day after spraying the treatment beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (1.16) had shown lower population and which was on par with fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} (1.27). The treatments thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (1.77) and thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (1.83) were statistically on par with each other. A higher population of whiteflies were recorded in plants treated with hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (2.88) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.44), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (2.33) and were statistically on par to

Figure. 7- Effect of insecticide mixture on population of whitefly, *Aleurothrixus trachoides*

Treatments	Number of whiteflies leaf $^{-1}$ (DAS)*						
	Pre count	1	3	5	7	10	15
Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 % ZC @ 33+15.75 g a.i ha^{-1}	4.83	2.44 ^{de} (0.90)	1.83 ^{c} (0.78)	1.72 ^{d} (1.00)	0.38 ^{d} (0.79)	0.00 ^{d} (0.70)	0.00 ^{c} (0.70)
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD 215.75+36.75 g a.i ha^{-1}	4.88	2.22 ^{ef} (0.86)	1.16 ^{d} (0.62)	0.66 ^{f} (0.84)	0.00 ^{e} (0.70)	0.00 ^{d} (0.70)	0.00 ^{c} (0.70)
Flubendiamide 19.92% + Thiacloprid 19.92 % SC @ 48+48 g a.i ha^{-1}	4.88	3.00 ^{bc} (0.99)	2.33 ^{b} (0.88)	2.05 ^{b} (1.08)	1.44 ^{b} (0.99)	0.55 ^{b} (0.82)	0.11 ^{bc} (0.74)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	4.94	1.88 ^{f} (0.79)	1.27 ^{d} (0.65)	0.00 ^{g} (0.70)	0.00 ^{e} (0.70)	0.00 ^{d} (0.70)	0.00 ^{c} (0.70)
Hand mixing of Spiromesifen 22.9% SC + Thiamethoxam 25 % WG (1:1) @ 96+50 g a.i ha^{-1}	4.94	3.33 ^{b} (1.05)	2.88 ^{b} (0.89)	1.77 ^{c} (1.04)	0.88 ^{c} (0.89)	0.33 ^{c} (0.78)	0.22 ^{b} (0.75)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	5.00	3.05 ^{bc} (1.00)	2.44 ^{b} (0.90)	2.00 ^{b} (1.07)	1.11 ^{bc} (0.93)	0.72 ^{b} (0.86)	0.22 ^{b} (0.76)
Thiamethoxam 25 % WG @50 g a.i ha^{-1}	5.00	2.77 ^{cd} (0.96)	1.77 ^{c} (0.76)	1.11 ^{e} (0.93)	0.00 ^{e} (0.70)	0.05 ^{d} (0.72)	0.11 ^{bc} (0.74)
Control	4.97	5.11 ^{a} (1.31)	5.88 ^{a} (1.40)	6.11 ^{a} (1.59)	6.22 ^{a} (1.60	6.44 ^{a} 1.67	7.94 ^{a} 1.77
CD (0.05)	NS	(0.073)	(0.073)	(0.033)	(0.069)	(0.040)	(0.047)

Figures in parentheses are √x+1 transformed values, DAS- Days after spraying, * Mean of 3 replications each other. The population of whiteflies in control plants (5.88) were higher among all other treatments and was significantly different from all.

The results obtained on the fifth day after spraying showed similar trend as in first day after spraying. No population of whiteflies were observed in plants treated with fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and was statistically superior from all other treatments. This was followed by the treatment beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.66) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (1.11). The treatments, flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48+ 48 g a.i ha^{-1} (2.05) and spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.00) were shown relatively higher population next to control (6.11).

The treatments beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50g a.i ha^{-1} were superior among all others and no whiteflies were observed in plants treated with these chemicals on seventh day after spraying followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.38), which was significantly different from the above treatments. The treatments, thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.38) and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (0.88) were significantly different from each other. However statistically higher population was observed in the treatment flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (1.44) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (1.11), next to control (6.22).

After ten days of spraying similar trend was observed. The treatments beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} had shown superiority over other treatments and no whiteflies were observed in the plants treated with these chemicals and were statistically on par with thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.05). Among the treatments higher population of whiteflies were observed in control plants (6.44) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.72) which was on par with flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.55).

On the fifteenth day after spraying the treatments thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1}, beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} were recorded with no population followed by thiamethoxam 25 % WG @ 50g a.i ha^{-1} (0.11), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.11) and were statistically on par. While, higher population was observed in spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.22) and hand mixed product of spiromesifen 22.9% SC and thiamethoxam 25 % WG @ 1:1 (0.22). The population of whiteflies were statistically higher in control plants (7.94) and was significantly different from all other treatments.

4.1.2. Thrips, *S. dorsalis*

The results on the efficacy of the insecticide mixtures on the population of thrips (thrips $leaf^{-1}$) in laboratory conditions are depicted in Table 8. The population of thrips was found to be non significant before spraying.

Beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.05) showed lower number of thrips after one day of spraying followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.16), fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.33) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.27) which were significantly different. The treatments thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 g a.i ha^{-1} (4.00), hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (3.83) and flubendiamide 19.92% + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (3.66) were statistically on par with each other and maintained relatively higher number of whiteflies next to control treatment (5.88).

On the third day after spraying the treatment beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (1.00) and fipronil 40 % +

Table. 8- Effect of insecticide mixtures on population of thrips, *Scirtothrips dorsalis*

Treatments	Number of thrips leaf^{-1} (DAS)*						
	Pre count	1	3	5	7	10	15
Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 % ZC @ 33+15.75 g a.i ha^{-1}	5.88	4.00^{b} (1.15)	2.66^{c} (0.95)	1.50^{c} (1.00)	0.77^{c} (0.72)	0.05^{d} (0.72)	0.05^{cd} (0.72)
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	5.83	2.05^{e} (0.83)	1.00^{e} (0.57)	0.00^{e} (0.70)	0.00^{e} (0.70)	0.00^{d} (0.70)	0.00^{d} (0.70)
Flubendiamide 19.92% + Thiacloprid 19.92 % SC @ 48+48 g a.i ha^{-1}	5.77	3.66^{b} (1.11)	2.55^{c} (0.93)	1.61^{c} (1.01)	0.61^{c} (0.72)	0.22^{c} (0.76)	0.11^{cd} (0.74)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	5.83	2.33^{d} (0.89)	1.00^{e} (0.58)	0.11^{e} (0.74)	0.00^{e} (0.70)	0.00^{d} (0.70)	0.00^{d} (0.70)
Hand mixing of Spiromesifen 22.9% SC + Thiamethoxam 25 % WG (1:1) @ 96+50 g a.i ha^{-1}	5.77	3.83^{b} (1.13)	3.38^{b} (1.06)	2.44^{b} (1.15)	1.50^{b} (0.75)	0.44^{b} (0.80)	0.27^{b} (0.77)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	5.77	2.16^{de} (0.85)	1.44^{d} (0.69)	0.88^{d} (0.89)	0.22^{d} (0.71)	0.00^{d} (0.70)	0.16^{c} (0.75)
Thiamethoxam 25 % WG @ 50 g a.i ha^{-1}	5.57	3.27^{c} (1.04)	2.27^{c} (0.87)	1.50^{c} (1.00)	0.22^{d} (0.71)	0.00^{d} (0.70)	0.11^{cd} (0.74)
Control	5.62	5.88^{a} (1.41)	6.55^{a} (1.47)	6.94^{a} (1.68)	7.33^{a} (0.87)	7.88^{a} (1.76)	8.11^{a} (1.79)
CD (0.05)	NS	(0.047)	(0.095)	(0.045)	(0.003)	(0.035)	(0.042)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying, * Mean of 3 replications

imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (1.00) showed lower number of thrips followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (1.44). The treatments thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 g a.i ha^{-1} (2.66), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (2.55) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.27) were statistically on par to each other. The plants treated with hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (3.38) were maintained higher number of thrips next to control (6.55).

After five days of spraying, thrips were not recorded in plants treated with beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.76 g a.i ha^{-1} followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.11) and were statistically on par. This was followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.88) and was significantly different from the above treatments. The treatments flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48+ 48 g a.i ha^{-1} (1.61), thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33+ 15.75g a.i ha^{-1} (1.50) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (1.50) were statistically on par. Whereas hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (2.44) showed higher number of thrips next to control (6.94).

No thrips were observed in treatments, beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} after seven days of spraying. This was followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} and spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.22 each). The treatments thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.77) and flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.61) were statistically on par. While hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (1.50) showed relatively higher number of thrips next to control (7.33)

After ten days of spraying more or less similar trend was observed. Beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil

40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1}, thiamethoxam 25 % WG @ 50 g a.i ha^{-1} and spiromesifen 22.9 % SC and were free from thrips followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.05) and were statistically on par. Comparing all the treatments, hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (0.44) showed higher number of thrips next to control (7.88).

Beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} were free from thrips after fifteen days of spraying. This was followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.05), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.11) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.11) which were statistically on par. The treatments spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.16) and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (0.27) were significantly different and followed after thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.05), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.11) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.11). The number of thrips in control plants were higher (8.11) compared to other chemical treatments.

4.1.3. Mite, *P. latus*

The effectiveness of insecticide mixtures was evaluated against the population of mite, *P. latus* (mites leaf $^{-1}$) in chilli under laboratory conditions is shown in Table 9.

The population of mite before spraying was found to be non significant. Among all the different treatments, spiromesifen 22.9 % SC 96 g a.i ha^{-1} (0.27) showed statistically lower number of mites after one day of spraying followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.11) , which were significantly different. This was followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.16). The four different

Table. 9- Effect of insecticide mixtures on population of mite, *Polyphagotarsonemus latus*

Treatments	Number of mite leaf $^{-1}$ (DAS)*						
	Pre count	1	3	5	7	10	15
Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 % ZC @ 33+15.75 g a.i ha^{-1}	6.05	4.00^{b} (1.15)	2.72^{c} (1.18)	1.61^{d} (1.01)	0.61^{d} (0.84)	0.16^{e} (0.74)	0.11^{d} (0.74)
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	6.00	3.16^{c} (1.02)	1.88^{d} (1.07)	0.16^{e} (0.75)	0.00^{e} (0.70)	0.00^{f} (0.70)	0.00^{e} (0.70)
Flubendiamide 19.92% + Thiacloprid 19.92 % SC @ 48+48 g a.i ha^{-1}	5.94	4.16^{b} (1.17)	3.38^{b} (1.27)	2.77^{c} (1.19)	2.11^{bc} (1.09)	1.44^{c} (0.99)	0.55^{c} (0.83)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	6.00	2.11^{d} (0.83)	1.00^{e} (0.92)	0.00^{f} (0.70)	0.00^{e} (0.70)	0.00^{f} (0.70)	0.00^{e} (0.70)
Hand mixing of Spiromesifen 22.9% SC + Thiamethoxam 25 % WG (1:1) @ 96+50 g a.i ha^{-1}	5.97	4.11^{b} (1.18)	2.77^{c} (1.19)	2.77^{c} (1.19)	1.94^{c} (1.08)	0.83^{d} (0.89)	0.11^{d} (0.74)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	5.71	0.27^{e} (0.31)	0.00^{f} (0.70)	0.00^{f} (0.70)	0.00^{e} (0.70)	0.00^{f} (0.70)	0.05^{de} (0.72)
Thiamethoxam 25 % WG @ 50 g a.i ha^{-1}	6.10	4.22^{b} (1.18)	3.72^{b} (1.31)	3.27^{b} (1.27)	2.27^{b} (1.13)	2.05^{b} (1.09)	2.22^{b} (1.12)
Control	6.21	6.16^{a} (1.44)	6.22^{a} (1.60)	6.33^{a} (1.62)	6.55^{a} (1.64)	6.77^{a} (1.66)	7.11^{a} (1.69)
CD (0.05)	NS	(0.056)	(0.058)	(0.043)	(0.049)	(0.039)	(0.035)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying, * Mean of 3 replications

treatments *viz*., thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (4.00), hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (4.11), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (4.16) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (4.22) were statistically on par and maintained higher number of mites after control treatment (6.16).

On the third day after spraying, the plants treated with spiromesifen 22.9 % SC 96 g a.i ha^{-1} were free from mites and significantly different from all other treatments. This was followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (1.00) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (1.88) and were significantly different also. The treatments, thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (2.72) and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (2.77) were statistically on par. Whereas thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.72) showed higher number of mites which was statistically on par with flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (3.38).

After five days of spraying, the treatments spiromesifen 22.9 % SC 96 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} were free from mites followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.16) and thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (1.61). The treatments, flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (2.77 each) were observed with higher number of mites. Among all the treatments, thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.27) had shown higher population of mites next to control (6.33) and was significantly different from all other treatments.

Similar trend in mortality was observed after seven days of spraying. The treatments beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and spiromesifen 22.9 % SC 96 g a.i ha^{-1} were free from mites. These treatments were followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.61) and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (1.94) and were significantly different. However thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.27) had shown statistically higher population of mites next to control (6.55).

On the tenth day after spraying, the treatments *viz.,* beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and spiromesifen 22.9 % SC 96 g a.i ha^{-1} were recorded with zero population of mites. These were followed by thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.16), hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (0.83), flubendiamide 19.92% + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (1.44) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.05) and were significantly different also. Thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.05) showed relatively higher population of mites after control (6.77).

Similar trend of mortality was observed after fifteen days of spraying. Beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} were free from mites followed by spiromesifen 22.9 % SC 96 g a.i ha^{-1} (0.05). These treatments were followed by thiamethoxam 12.6 % +lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (0.11), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.55), hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (0.11) and thiamethoxam 25% WG @ 50 g a.i ha^{-1} (2.22).

4.1.4. Aphids, *A. gossypii*

The effectiveness of insecticide mixtures was evaluated against the population of aphids, *A. gossypii* in chilli under laboratory conditions is shown in Table 10.

Table. 10- Effect of insecticide mixtures on population of aphids, *Aphis gossypii*

Treatments	Number of aphids $leaf^{-1}$ (DAS)*						
	Pre count	1	3	5	7	10	15
Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 % ZC @ 33+15.75 g a.i ha^{-1}	6.79	4.00 ^{e} (1.16)	2.83 ^{de} (0.98)	1.72 ^{d} (1.04)	1.00 ^{d} (0.92)	0.00 ^{e} (0.70)	0.00 ^{d} (0.70)
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	6.79	3.11 ^{f} (1.01)	2.27 ^{fg} (0.87)	1.11 ^{e} (0.89)	0.00 ^{f} (0.70)	0.00 ^{e} (0.70)	0.00 ^{d} (0.70)
Flubendiamide 19.92% + Thiacloprid 19.92 % SC @ 48+48 g a.i ha^{-1}	6.80	5.33 ^{c} (1.34)	3.55 ^{c} (1.09)	2.55 ^{c} (1.16)	1.66 ^{c} (1.03)	0.44 ^{d} (0.80)	0.16 ^{c} (0.75)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	6.79	2.88 ^{f} (0.99)	2.16 ^{g} (0.85)	0.16 ^{f} (0.75)	0.00 ^{f} (0.70)	0.00 ^{e} (0.70)	0.00 ^{d} (0.70)
Hand mixing of Spiromesifen 22.9% SC + Thiamethoxam 25 % WG (1:1) @ 96+50 g a.i ha^{-1}	6.80	4.61 ^{d} (1.24)	3.33 ^{cd} (1.05)	2.44 ^{c} (1.15)	1.88 ^{c} (1.07)	0.66 ^{c} (0.84)	0.22 ^{c} (0.76)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	6.80	6.44 ^{b} (1.47)	4.83 ^{b} (1.26)	4.00 ^{b} (1.36)	3.11 ^{b} (1.23)	2.27 ^{b} (1.12)	2.33 ^{b} (1.13)
Thiamethoxam 25 % WG @ 50 g a.i ha^{-1}	6.80	3.77 ^{e} (1.12)	2.66 ^{ef} (0.95)	1.44 ^{d} (0.99)	0.27 ^{e} (0.77)	0.00 ^{e} (0.70)	0.00 ^{d} (0.70)
Control	6.81	6.88 ^{a} (1.68)	8.66 ^{a} (1.69)	9.11 ^{a} (1.87)	9.38 ^{a} (1.90)	9.50 ^{a} (1.92)	9.88 ^{a} (1.95)
CD (0.05)	NS	(0.068)	(0.092)	(0.051)	(0.053)	(0.030	(0.048)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying, * Mean of 3 replications

The population of aphids before spraying was found to be uniform. On the first day after spraying fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.88) showed lower number of aphids and was statistically on par with beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.11). This was followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.77) and thiamethoxam 12.6 % +lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (4.00) and were on par. The treatments, hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (4.61), flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (5.33) and spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (6.44) were significantly different from each other and followed after thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.77) and thiamethoxam 12.6 % +lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (4.00). Among all the seven chemicals spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (6.44) showed statistically higher population of aphids after control (6.88).

On the third day after spraying fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.16) showed statistically lower population of aphids followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.27), thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.66) and thiamethoxam 12.6 % +lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (2.83), and were significantly different. These treatments were followed by hand mixed product of spiromesifen 22.9% SC and thiamethoxam 25 % WG @ 1:1 (3.33) and flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (3.55), which were significantly different also. Immediately after control treatment (8.66) spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.83) showed statistically higher number of aphids and was significantly different from all other treatments.

Similar trend in reduction in population of aphids were observed after five days of spraying. Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.16) showed significantly lower population. This was followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (1.11), thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (1.44) and thiamethoxam 12.6 % +

lambda cyhalothrin 9.5 % ZC @ 33 + 15.76 g a.i ha^{-1} (1.72), which were significantly different from fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.16). The treatments, hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (2.44) and flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (2.55) were statistically on par. The treatment spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.00) showed statistically higher number of aphids, among all the treatments.

A similar pattern of reduction in population of aphids were observed on seventh day after spraying. Beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} were recorded free from aphids and were significantly different from all other treatments. These were followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.27), thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1} (1.00). The treatments flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (1.66) and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (1.88) were statistically on par to each other but significantly different from fipronil 40 % + imidacloprid 40 % WG @ 175 + 175g a.i ha^{-1} (0.00). Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (3.11) was recorded with significantly higher population of aphids next to control (9.38).

Thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1}, beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} were free from aphids after ten days of spraying which were significantly different from all other treatments. These were followed by flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.44), hand mixed product of spiromesifen 22.9 % SC and thiamethoxam 25 % WG @ 1:1 (0.66), which were significantly different. Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.27) showed significantly higher population of aphids among all the treatments, after control (9.50).

Similar trend in reduction in number of aphids were observed after fifteen days of spraying. The treatments thiamethoxam 12.6 % + lambda cyhalothrin 9.5

% ZC @ 33 + 15.75 g a.i ha^{-1}, beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} were free from aphids. These were followed by flubendiamide 19.92 % + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1} (0.16) and hand mixed product of spiromesifen 22.9 % SC and thiamethoxam @ 1:1 (0.22), which were statistically on par. The treatment spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.33) showed significantly higher number of aphids among all the treatments, next to control (9.88).

4.2. FIELD EVALUATION OF SELECTED INSECTICIDE MIXTURES AGAINST SUCKING PESTS OF CHILLI

Based on the preliminary evaluation, four effective insecticides *viz.,* beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD, fipronil 40 % + imidacloprid 40 % WG, spiromesifen 22.9 % SC and thiamethoxam 25 % WG along with untreated control were selected for conducting field experiment against the major sucking pests of chilli. The results presented in Table. 11 to 14.

4.2.1. Whitefly, *A. trachoides*

The efficacy of insecticide mixtures against whiteflies, *A. trachoides* in chilli (whiteflies $leaf^{-1}$) under field conditions is shown in Table 11.

The population of whiteflies before spraying was found to be uniform and thus it was non significant. A significant lower number of whiteflies were observed in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (3.30) after first day of spraying and was significantly different from all other treatments. It was followed by beta cyfluthrin 8.9 1% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.36) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.96), which were statistically on par to each other. Significantly higher population of whiteflies were observed in control (6.43) which was significantly different from spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.93).

Table. 11 – Effect of insecticide mixtures on population of whiteflies, *Aleurothreixus trachoides* under field conditions

Treatments	Number of whiteflies leaf^{-1} (DAS)*						
	Pre count	1	3	5	7	10	15
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	6.40	3.36 ^{d} (1.83)	3.16 ^{d} (1.77)	2.80 ^{c} (1.67)	0.60 ^{d} (0.76)	0.10 ^{d} (0.77)	0.06 ^{d} (0.75)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	6.43	3.30 ^{d} (1.81)	3.03 ^{d} (1.74)	2.73 ^{c} (1.65)	0.43 ^{d} (0.64)	0.10 ^{d} (0.77)	0.00 ^{d} (0.70)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	6.30	5.93 ^{b} (2.43)	5.80 ^{b} (2.40)	5.06 ^{b} (2.25)	3.06 ^{b} (1.75)	1.60 ^{b} (1.44)	0.86 ^{b} (1.16)
Thiamethoxam 25 %WG @ 50 g a.i ha^{-1}	6.41	3.96 ^{c} (1.99)	3.50 ^{c} (1.87)	2.86 ^{c} (1.69)	2.23 ^{c} (1.49)	0.90 ^{c} (1.18)	0.43 ^{c} (0.96)
Control	6.39	6.43 ^{a} (2.53)	7.66 ^{a} (2.76)	7.96 ^{a} (2.82)	8.00 ^{a} (2.82)	7.73 ^{a} (2.86)	7.83 ^{a} (2.88)
CD (0.05)	NS	(0.064)	(0.066)	(0.058)	(0.134)	(0.088)	(0.071)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying, * Mean of 10 plants

On the third day after spraying, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (3.03) followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.16) were recorded with lower number of whiteflies and were statistically on par. Number of whiteflies in thiamethoxam 25 % WG @ 50g a.i ha^{-1} (3.50) was lower. Whereas spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.80) recorded significantly higher population of whiteflies which was statistically lower than control (7.66).

The treatment fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.73) showed significantly lower population of whiteflies followed by, betacyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.80) and, were statistically on par and significantly different from control (7.96) on fifth day of spraying. The population of whiteflies were significantly higher in spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.06) next to control (7.96).

Similar trend of population was observed in seventh day after spraying. Among all the treatments, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.43) showed significantly lower population followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.60) and were statistically on par and significantly different from all others. Next to control (8.00), spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (3.06) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.23) showed significantly higher population of whiteflies and were significantly different.

On the tenth day of spraying, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and beta cyfluthrin 8.9 1% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.10) had shown statistically lower population of whiteflies. Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (1.60) had recorded significantly higher population next to control (7.73) followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.90) and were significantly different.

Similar trend of population dynamics was observed in fifteenth day after spraying. No whiteflies were observed in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.06) and they were statistically on par.

Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.86) recorded significantly higher population next to control (7.83) followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.43) and were significantly different.

4.2.2. Thrips, *S. dorsalis*

The efficacy of insecticide mixtures against chilli thrips, *S. dorsalis* under field conditions (thrips $leaf^{-1}$) is shown in Table. 12. The population of thrips before spraying was found to be uniform and thus it was non significant.

Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (3.13) showed statistically lower population of thrips on the first day after spraying. It was followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.70), beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.93) and, which were statistically different also. While, higher number of thrips were recorded in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (6.60) next to control (7.80), and was significantly different from all treatments.

Similar pattern of population dynamics of thrips was observed after three days of spraying. Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.96) showed significantly lower population of thrips followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.40), and these were significantly different. Next to control treatment (8.26), thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (6.03) showed statistically higher population of thrips, followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.40) and they were significantly different.

The reduction in the population of thrips on the fifth day after spraying followed the same pattern as that of third day. Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (2.16) showed statistically lower population of thrips. Thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (5.43) was the treatment having statistically higher population of thrips next to control (8.36), followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (3.43) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.03), which were significantly different.

Table. 12 – Effect of insecticide mixtures on population of thrips, *Scirtothrips dorsalis* under field conditions

Treatments	Number of thrips leaf^{-1} (DAS)*						
	Pre count	1	3	5	7	10	15
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	7.79	3.93^{d} (1.98)	3.40^{d} (1.84)	3.03^{d} (1.74)	1.73^{d} (1.49)	0.26^{c} (0.87)	0.06^{d} (0.74)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	8.10	3.13^{e} (1.76)	2.96^{e} (1.72)	2.16^{e} (1.47)	0.13^{e} (0.79)	0.00^{d} (0.70)	0.00^{e} (0.70)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	8.02	4.70^{c} (2.16)	4.40^{c} (2.09)	3.43^{c} (1.85)	2.23^{c} (1.65)	1.30^{b} (1.34)	0.50^{c} (0.75)
Thiamethoxam 25 %WG @ 50 g a.i ha^{-1}	7.97	6.60 b (2.56)	6.03^{b} (2.45)	5.43^{b} (2.32)	3.76^{b} (2.06)	1.33^{b} (1.35)	0.56^{b} (1.02)
Control	7.54	7.80^{a} (2.79)	8.26^{a} (2.87)	8.36^{a} (2.89)	8.20^{a} (2.94)	8.23^{a} (2.95)	8.92^{a} (3.06)
CD (0.05)	NS	(0.058)	(0.042)	(0.087)	(0.097)	(0.072)	(0.002)

Figures in parentheses are √x+1 transformed values, DAS- Days after spraying, * Mean of 10 plants

On the seventh day after spraying, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} recorded lower population of thrips (0.13) followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (1.73) and spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.23), which were stignificantly different. Among all the treatments, thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.76) showed higher population of thrips next to control treatment (8.20).

No thrips were found in treatment, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} after ten days of spraying and was significantly different from all other treatments. This was followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.26). Apart from Control (8.23), statistically higher population of thrips was observed in thiamethoxam 25 % WG @ 50 g a.i ha^{-1}(1.33) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (1.30) and were statistically on par.

On the fifteenth day after spraying, no population of thrips was found in fipronil 40 % +imidacloprid 40 % WG @ 175g a.i ha^{-1} followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.06) and were significantly different. Other than control treatment (8.92) a significant higher population of thrips was shown by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.56) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.50), which were significantly different.

4.2.3. Chilli mite, *P. latus*

The efficacy of insecticide mixtures were evaluated against chilli mite, *P. latus* and results (mite $leaf^{-1}$) are shown in Table 13. The population of mites were almost similar in all the treatment plots before spraying and thus it was non significant.

Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (3.30) recorded significantly lower population of mites on the first day after spraying and was significantly different from all other treatments. This was followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (4.13) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (4.30) and were statistically

Table. 13 – Effect of insecticide mixtures on population of mite, *Polyphagotarsonemus latus* under field conditions

Treatments	Number of mites $leaf^{-1}$ (DAS)*						
	Pre count	1	3	5	7	10	15
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	7.09	4.30 ^{c} (2.03)	3.60 ^{c} (1.89)	3.26 ^{c} (1.93)	2.30 ^{c} (1.67)	1.63 ^{c} (1.45)	0.00 ^{c} (0.70)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	7.10	4.13 ^{c} (2.00)	3.46 ^{c} (1.86)	2.96 ^{c} (1.86)	1.63 ^{d} (1.45)	1.10 ^{d} (1.26)	0.00 ^{c} (0.70)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	7.00	3.30 ^{d} (1.81)	2.60 ^{d} (1.61)	0.16 ^{d} (0.81)	0.00 ^{e} (0.70)	0.00 ^{e} (0.70)	0.00 ^{c} (0.70)
Thiamethoxam 25 %WG @ 50 g a.i ha^{-1}	7.10	6.00 ^{b} (2.44)	4.00 ^{b} (1.99)	3.83 ^{b} (2.08)	2.46 ^{b} (1.72)	1.73 ^{b} (1.49)	1.56 ^{b} (1.43)
Control	7.07	7.10 ^{a} (2.66)	7.53 ^{a} (2.74)	7.50 ^{a} (2.82)	7.50 ^{a} (2.82)	7.56 ^{a} (2.84)	8.03 ^{a} (2.92)
CD (0.05)	NS	(0.062)	(0.055)	(0.089)	(0.086)	(0.098)	(0.013)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying, * Mean of 10 plants on par. Thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (6.00) was the treatment showing higher population of mite next to control (7.10).

On the third day after spraying, Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (2.60) showed lower population of mite and was significantly different from all others. This was followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (3.46) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (3.60), were statistically on par, and significantly different from thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (4.00). A higher number of mite population was observed in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (4.00).

The reduction in population of mite on fifth day after spraying followed the similar pattern as that of third day after spraying. Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.16) showed statistically lower population of mite and was significantly different from all other treatments. This was followed by fipronil 40 % + imidacloprid 40 % WG @175 + 175 g a.i ha^{-1} (2.96) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD@ 15.75 + 36.75 g a.i ha^{-1} (3.26), were statistically on par, and significantly different from thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.83). Next to control (7.50), thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (3.83) showed significantly higher population of mite.

No population of mite was observed in spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} after seventh day of spraying followerd by fipronil 40 % + imidacloprid 40 % WG @ 175+ 175 g a.i ha^{-1} (1.63) and were significantly different. Whereas statistically higher population of mite was observed in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.46) followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.30) and were statistically different.

A similar pattern of reduction in population of mites were observed in tenth day after spraying. No population of mites were observed in spiromesifen 22.9% SC @ 96 g a.i ha^{-1}, followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha (1.10) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (1.63). Next to control treatment (7.56) a significant higher population of mites were observed in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (1.73).

After fifteenth day of spraying, no population of mites were observed in beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and spiromesifen 22.9% SC @ 96 g a.i ha^{-1}. While a significant higher population was recorded in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (1.56).

4.2.4. Aphid, *A. gossypii*

The effectiveness of insecticide mixtures on the field population of aphids, *A. gossypii* (aphids $leaf^{-1}$) were evaluated and the results are shown in Table 14. The population were found to be almost similar in all the treatment plots before spraying and thus it was non significant.

Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (8.36) showed significantly lower population immediately after first day of spraying and was statistically different from all other treatments. This was followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (9.55) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (10.46) and were statistically different from other treatments. A significantly higher population was recorded in spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (16.24) and was statistically different from control treatment (20.58).

On the third day after spraying, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (7.33) showed significantly lower population of aphids. This was followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (8.90) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (8.91) which were statistically on par to each other, but different from fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (7.33). Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (14.50) showed statistically higher population.

Table. 14 – Effect of insecticide mixtures on population of aphids, *Aphis gossypii* under field conditions

Treatments	Number of aphids leaf^{-1} (DAS)*						
	Pre count	1	3	5	7	10	15
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	19.27	9.55^{d} (3.09)	8.91^{c} (2.98)	2.96^{d} (1.72)	0.60^{d} (0.77)	0.03^{d} (0.72)	0.00^{c} (0.70)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	19.30	8.36^{e} (2.89)	7.33^{d} (2.70)	1.83^{e} (1.35)	0.52^{e} (0.72)	0.00^{e} (0.70)	0.00^{c} (0.70)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	20.00	16.24^{b} (4.02)	14.50^{b} (3.80)	12.25^{b} (3.50)	9.36^{b} (3.06)	8.12^{b} (2.93)	9.17^{b} (3.10)
Thiamethoxam 25 %WG @ 50 g a.i ha^{-1}	20.01	10.46^{c} (3.23)	8.90^{c} (2.98)	7.91^{c} (2.81)	5.81^{c} (2.41)	4.15^{c} (2.15)	0.05^{c} (0.74)
Control	19.33	20.58^{a} (4.53)	26.58^{a} (5.15)	33.21^{a} (5.76)	39.52^{a} (6.28)	43.10^{a} (6.60)	45.99^{a} (6.81)
CD (0.05)	NS	(0.046)	(0.074)	(0.007)	(0.038)	(0.007)	(0.071)

Figures in parentheses are √x+1 transformed values, DAS- Days after spraying, * Mean of 10 plants

The effect of all the five treatments were significantly different from each other on fifth day after spraying. Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (1.83) showed statistically lower population of aphids followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.96) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (7.91). Next to control (33.21), spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (12.25) maintained higher population of aphids.

A similar pattern of reduction in population of aphids were observed after seventh day of spraying. Fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.52) showed significantly lower population of aphids followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha (0.60) and were statistically different. This was followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (5.81) which was significantly different from the above treatments. Whereas spiromesifen 22.9% SC @ 96 g a.i ha^{-1} (9.36) showed higher population next to control treatment (39.52) and were significantly different.

No population of aphids were seen after ten days of spraying in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.03) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (4.15). However spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (8.12) showed a significant higher population even after ten days of spraying and was statistically different from control treatment (43.10).

More or less similar pattern of reduction in population of aphids were noticed after fifteen days of spraying. No population were observed in beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.05) after fifteen days of spraying. But, compared to other treatments, spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (9.17) showed a significant higher population of aphids next to control (45.99).

4.3. Leaf Curl Index (LCI)

Intensity of leaf curl caused by *P. latus, S. dorsalis* or both was worked out as per standard procedure for scoring and is depicted in Table 15.

LCI on the previous day of spraying showed that, there was no significant difference between the treatments.

At 15 days after spraying (DAS), the lowest leaf curl index (LCI) was recorded in spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.04) followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.08 each) which were on par with each other and significantly different from spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (0.04). The LCI observed in untreated control was 3.94 and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} was 0.22.

At 30 DAS no leaf curl was observed in beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} and these were statistically superior to other two treatments. Whereas an average LCI of 0.02 was observed thiamethoxam 25 % WG @ 50 g a.i ha^{-1}, which was statistically on par with the above treatments. The control plants had a higher LCI of 3.96.

Similar pattern of LCI was observed at 45 DAS. Spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} were showed LCI of zero category followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.06) which was significantly different. Control plant showed significantly higher LCI of 4.00 followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.12).

Table. 15 – Leaf curl index in chill at different intervals after spraying with insecticides

Treatments	LCI		
	15 DAS	30 DAS	45 DAS
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	0.08 (0.76)	0.00 (0.70)	0.06 (0.74)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	0.08 (0.76)	0.00 (0.70)	0.00 (0.70)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	0.04 (0.73)	0.00 (0.70)	0.00 (0.70)
Thiamethoxam 25 % WG @ 50 g a.i ha^{-1}	0.22 (0.84)	0.02 (0.72)	0.12 (0.78)
Control	3.94 (2.10)	3.96 (2.11)	4.00 (2.12)
CD (0.05)	(0.036)	(0.019)	(0.023)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying

4.4. SAFETY EVALUATION OF SELECTED INSECTICIDES AGAINST COCCINELLID BEETLES AND SPIDERS

The effect of different insecticides on the population of coccinellids and spiders are presented in Table 16 to 17.

4.4.1. Coccinellid Beetles

On the first day after spraying, relatively higher population of beetles were seen in plants sprayed with spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.2), but it was lower than control (7.4). A significant lower population of beetles were found in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.20) followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.40), which were statistically on par with each other and not on par with thiamethoxam 25 % WG @ 50 g a.i ha^{-1}. No coccinellid beetles were observed in plants treated with thiamethoxam 25 % WG @ 50 g a.i ha^{-1}. (Table. 16)

Significantly higher population of beetles were seen in control (7.8) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.2) on third day after spraying and were significantly different. No coccinellid beetles were observed in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1}, and they were not on par with beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.20).

Apart from control (8.00), statistically superior population of coccinellids were found spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.80) on fifth day after spraying. Similar to third day after spraying, no beetles were seen in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and were statistically on par.

Similar pattern of toxicity of insecticide towards coccinellids were observed in seventh day after spraying also. Control (8.40) plants had maximum population of beetles followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.60). No beetles were observed in fipronil 40 % + imidacloprid 40 % WG @ 175 + 175

Table.16 – Mean population of adult coccinellids at different intervals after spraying

Treatments	Mean population of coccinellid / 6 plants (DAS)						
	Pre count	1	3	5	7	10	15
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	7.32	0.40^{c} (0.88)	0.20^{c} (0.81)	0.00^{c} (0.70)	0.00^{c} (0.70)	0.00^{c} (0.70)	0.00^{d} (0.70)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	7.30	0.20^{c} (0.81)	0.00^{c} (0.70)	0.00^{c} (0.70)	0.00^{c} (0.70)	0.60^{c} (0.98)	1.00^{c} (1.19)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	7.30	5.20^{b} (2.38)	5.20^{b} (2.38)	4.80^{b} (2.30)	4.60^{b} (2.25)	5.60^{b} (2.46)	7.80^{b} (2.87)
Thiamethoxam 25 % @ 50 g a.i ha^{-1}	7.30	0.00^{d} (0.70)	0.00^{c} (0.70)	0.00^{c} (0.70)	0.00^{c} (0.70)	0.20^{c} (0.81)	0.80^{c} (1.08)
Control	7.31	7.40^{a} (2.83)	7.80^{a} (2.87)	8.00^{a} (2.91)	8.40^{a} (2.98)	8.40^{a} (2.98)	10.40^{a} (3.29)
CD (0.05)	NS	(0.283)	(0.162)	(0.180)	(0.225)	(0.236)	(0.338)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying

g a.i ha^{-1}, thiamethoxam 25 % WG @ 50g ai ha^{-1} and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75g ai ha^{-1} and were statistically on par.

Apart from control plants (8.40), spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.60) showed significantly higher population of beetles and was significantly different from all other treatments on tenth day after spraying. The plants sprayed with beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} showed no population of coccinellids followed by thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.20) and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.60).

A significant higher population of beetles were observed in spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (7.80) on fifteenth day after spraying after control (10.40). It was followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (1.00) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.80) and were statistically on par to each other, but significantly different from all other treatments. Whereas the plants treated with beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} showed no population of beetles.

4.4.2. Spiders.

On the first day after spraying, a higher population of spiders were seen in control (4.40) and was statistically on par with spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (3.20) followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.40 each) and they were statistically on par. Significantly lower population of spiders was observed in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.20). (Table. 17).

Similar pattern of toxicity towards spiders was observed on third day after spraying also. A higher population of spiders were seen in control (5.60) and was not statistically on par with spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.60). these were followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.40) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g

Table.17 – Mean population of spiders at different intervals after spraying

Treatments	Mean population of spiders / 6 plants (DAS)						
	Pre count	1	3	5	7	10	15
Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD @ 15.75+36.75 g a.i ha^{-1}	4.41	0.40 c (0.91)	0.20 b (0.81)	0.00 c (0.70)	0.00 c (0.70)	0.40 c (0.91)	0.60 c (0.98)
Fipronil 40% + Imidacloprid 40% WG @ 175+175 g a.i ha^{-1}	4.40	0.40 c (0.91)	0.40 b (0.91)	0.00 c (0.70)	0.00 c (0.70)	0.40 c (0.91)	0.80 c (1.08)
Spiromesifen 22.9% SC @ 96 g a.i ha^{-1}	4.40	3.20 b (1.92)	4.60 a (2.25)	4.20 b (2.16)	5.00 b (2.34)	6.40 b (2.61)	6.60 b (2.66)
Thiamethoxam 25 % @ 50 g a.i ha^{-1}	4.41	0.20 c (0.81)	0.00 b (0.70)	0.00 c (0.70)	0.00 c (0.70)	0.20 c (0.81)	0.60 c (0.98)
Control	4.40	4.40 a (2.21)	5.60 a (2.46)	6.80 a (2.69)	7.00 a (2.73)	8.00 a (2.90)	9.20 a (3.10)
CD (0.05)	NS	(0.326)	(0.251)	(0.227)	(0.116)	(0.283)	(0.349)

Figures in parentheses are $\sqrt{x+1}$ transformed values, DAS- Days after spraying

a.i ha^{-1} (0.20) and were statistically on par. No population of spiders were recorded in thiamethoxam 25 % WG @ 50 g a.i ha^{-1}.

On the fifth day after spraying, a significantly higher population were seen in control (6.80) followed by spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (4.20) and were statistically not on par. The plants sprayed with by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, thiamethoxam 25 % WG @ 50 g a.i ha^{-1} and by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} showed no population of spiders.

A significant higher population of spiders were seen control (7.00), after seventh day of spraying which was statistically not on par with spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} (5.00). The treatments beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, fipronil 40% + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g ai ha^{-1}recorded no population of spiders.

The population of spiders were significantly higher in control (8.00) followed by spiromesifen 22.9% SC @ 96 g a.i ha^{-1} (6.40) on tenth day after spraying and were statistically different. These were followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.40) and beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.40). A significant lower population of spiders were seen in thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.20).

On the fifteenth day after spraying, next to control (9.20), a higher population of spiders were seen in spiromesifen 22.9% SC @ 96 g a.i ha^{-1} (6.60), which was statistically different from all other treatments. These were followed by fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} (0.80). A significant lower population of spiders were observed in beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (0.60 each).

4.5 PERSISTENCE AND DISSIPATION OF INSECTICIDE RESIDUES IN CHILLI

4.5.1 Method Validation and Recovery of Insecticide for Pesticide Residue Analysis in Chilli

The results of the validation for the estimation of the different insecticides in chilli showed satisfactory recovery. Method validation accomplished with good linearity and acceptable recoveries. The mean recovery of all the insecticides under study was within the acceptance range of 70 – 120 per cent at all three levels of fortification. The repeatability of the recovery as indicated by relative standard deviation, RSD < 20 per cent, confirmed that the method was sufficiently reliable for pesticide analysis and the results are presented in Table 18.

4.5.2 Estimation and Dissipation Percentage of Pesticide Residues in Chilli

The average residues, its dissipation percentage and half-lives are depicted in Table 19 to 21.

4.5.2.1 Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD

Beta cyfluthrin

Immediately after two hours of spraying, an initial high amount of residue (0.49 mg kg^{-1}) was noticed on chilli. It dissipated to 5.55 per cent and reached to a residue of 0.34 mg kg^{-1} on first day after spraying. The residues observed on third day after spraying was 0.33 mg kg^{-1} with a dissipation percentage of 32.65. A residue amount of 0.16 mg kg^{-1} was observed on fifth day after spraying and the dissipation rate was 67.34 per cent. On seventh and tenth day after spraying an average residues of 0.08 and 0.06 mg kg^{-1} were noticed with a dissipation percentage of 83.67 and 87.75 respectively. The residues reached below LOQ on fifteenth day after spraying onwards. The calculated half- life for beta cyfluthrin was 4.82 days.

Table. 18 Per cent recovery of insecticides in chilli fruits

Insecticides	Fortification levels (mg kg^{-1})					
	0.05		0.25		0.50	
	Mean recovery (%)	RSD (%)	Mean recovery (%)	RSD (%)	Mean recovery (%)	RSD (%)
Lambda cyhalothrin	120.00	1.67	120.00	5.88	115.00	5.91
Thiamethoxam	84.00	8.25	101.33	4.56	77.83	12.22
Beta cyfluthrin	74.00	0.50	76.00	2.60	84.00	1.80
Imidacloprid	96.00	2.08	84.00	4.17	84.00	4.76
Fipronil*	116.00	0.30	116.00	2.70	102.00	0.00
Flubendiamide	110.67	5.52	120.00	5.77	104.67	10.52
Thiacloprid	85.67	1.78	89.33	2.59	77.33	5.29
Spiromesifen	98.70	2.55	99.40	5.60	94.60	9.08

Limit of quantification (LOQ) – 0.05 mg kg^{-1}, RSD- Relative standard deviation

*Fortification levels @ 0.001, 0.005 and 0.010 mg kg^{-1} with 0.001 mg kg^{-1} as LOQ

Table. 19 Residue of beta cyfluthrin 8.91% + imidacloprid 19.81 % OD in chilli fruits

DAS	Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD			
	Beta cyfluthrin		Imidacloprid	
	Mean residue (mg kg^{-1})	Dissipation (%)	Mean residue (mg kg^{-1})	Dissipation (%)
Before application	LOQ			
0 (2 h after spraying)	0.49	-	0.18	-
1	0.34	30.61	0.17	5.55
3	0.33	32.65	0.13	27.77
5	0.16	67.34	0.07	61.11
7	0.08	83.67	< LOQ	
10	0.06	87.75	< LOQ	
15	< LOQ	-	< LOQ	
30	< LOQ	-	< LOQ	
Half life (Days)	4.82		3.62	

DAS – Days after Spraying, LOQ- Limit of quantification (0.05 mg kg^{-1})

Imidacloprid

The initial residue of imidacloprid on chilli was observed as 0.18 mg kg^{-1}. It was dissipated to 5.55 per cent and reached to a mean residue of 0.17 mg kg^{-1} on first day after spraying. On third day after spraying, the mean residue observed was 0.13 mg kg^{-1} with dissipation percentage of 27.77. On fifth day after spraying, a lowest residue of 0.07 mg $kg^{-1}$was noticed with 61.11 per cent dissipation rate. From seventh day onwards, the residues reached below LOQ category. The half- life for imidacloprid was calculated as 3.62 days.

4.5.2.2 Fipronil 40% + Imidacloprid 40% WG

Fipronil

The residues of fipronil reached below LOQ on the day of spraying itself.

Imidacloprid

The initial residue of imidacloprid wasobserved as 0.09 mg kg^{-1}. It was dissipated to 33.33 per cent and reached to 0.06 mg kg^{-1} on first day after spraying. The residues of imidacloprid reached below LOQ on third day after spraying. The half- life of imidacloprid in Fipronil 40 % + Imidacloprid 40 % WG mixture was calculated as 0.02 days.

4.5.2.3 Spiromesifen 22.9 % SC as Single Insecticide

The initial deposit of spiromesifen was found as 0.92 mg kg^{-1}. It was dissipated to 26.08 per cent and reached to 0.68 mg kg^{-1}on first day after spraying. The residues of spiromesifen on 3, 5, 7 and 10 days after spraying was found as 0.58, 0.53, 0.22 and 0.21 mg kg^{-1} respectively. The residues reached below LOQ from 15^{th} day after spraying onwards. The half- life of spiromesifen on chilli was calculated as 4.49 days.

4.5.2.4 Thiamethoxam 25 % WG as Single Insecticide

The residues of thiamethoxam on chilli reached below LOQ at fifth day after spraying onwards. The initial residue was observed as 0.17 mg kg^{-1}. On the

Table. 20 Residue of fipronil 40% + imidacloprid 40% WG in chilli fruits

DAS	Fipronil 40% + Imidacloprid 40% WG		
	Fipronil*	Imidacloprid	
	Mean residue (mg kg^{-1})	Mean residue s (mg kg^{-1})	Dissipation (%)
Before application	LOQ	LOQ	
0 (2 h after spraying)	< LOQ	0.09	-
1	< LOQ	0.06	33.33
3	< LOQ	< LOQ	
Half life (Days)		0.02	

DAS – Days after Spraying, LOQ- Limit of quantification (0.05 mg kg^{-1})

*Limit of quantification of Fipronil- 0.001 mg kg^{-1}

Table. 21 Residue of spiromesifen 22.9% SC and thiamethoxam 25 % WG on chilli fruits

DAS	Spiromesifen 22.9% SC		Thiamethoxam 25 % WG	
	Mean residue (mg kg^{-1})	Dissipation (%)	Mean residue (mg kg^{-1})	Dissipation (%)
Before application	LOQ		LOQ	
0 (2 h after spraying)	0.92	-	0.17	-
1	0.68	26.08	0.09	47.05
3	0.58	36.95	0.07	58.82
5	0.53	42.39	< LOQ	
7	0.22	76.08	< LOQ	
10	0.21	77.17	< LOQ	
15	< LOQ		< LOQ	
Half life (Days)	4.49		2.51	

DAS – Days after Spraying, LOQ- Limit of quantification (0.05 mg kg^{-1})

first day after spraying, the initial residues degraded at the rate of 47.05 per cent and reached to an amount of 0.09 mg kg^{-1}. On the third day after spraying, an average residue of 0.07 mg kg^{-1} was observed with a dissipation percentage of 58.82. The calculated half- life was 2.51 days.

4.6 RISK ASSESSMENT OF INSECTICIDE MIXTURES ON CHILLI FRUITS

Risk assessment is purely a theoretical calculation to ensure that the product is safe when offered for consumption based on the residue present. The primary aim of the risk assessment is to determine the safe levels of dietary exposure of agricultural chemicals to human beings and the environment. The repeated and prolonged use of pesticides on crops leads to high amount residues and the consumption of pesticide laden commodities may lead to adverse health related issues.

Risk assessment was estimated by comparing the acceptable daily intake (ADI) value with maximum permissible intake (MPI) of residues of pesticide through the produce and the theoretical maximum residue contribution (TMRC). ADI value recommended by WHO (2012) was used for risk assessment. An average Indian consumes 5 g of fresh chilli in a balanced diet (NSSO, 2014). The MPI was obtained by multiplying the ADI with the average weight of Indian person, 60 kg. (Katna *et al.,* 2017). If the TMRC values are lesser than the MPI values, then the risk is said to be zero and the produce is safer for human consumption. The risk assessment of insecticide mixtures are presented in Table 22 to 24.

4.6.1 Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD

The risk assessment of Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD is shown in Table 22.

Beta cyfluthrin

The ADI value of beta cyfluthrin is 0.04 mg kg^{-1} bw day^{-1}. The MPI value was 2400 μg $person^{-1}$ day^{-1}. The TMRC values calculated for beta cyfluthrin at 0,

Table. 22 Risk assessment of beta cyfluthrin 8.91% + imidacloprid 19.81 % OD in chilli fruits

ADI (mg kg^{-1} bw d^{-1})		Average body weight (kg)	Interval (Days)	Daily Consumption rate (g day^{-1})	MPI (µg $person^{-1}$ day^{-1})		Average residue (µg g^{-1})		TMRC (µg $person^{-1}$ day^{-1})	
Beta cyfluthrin	Imidacloprid				Beta cyfluthrin	Imidacloprid	Beta cyfluthrin	Imidacloprid	Beta cyfluthrin	Imidacloprid
0.04	0.06	60	0	5	2400	3600	0.49	0.18	2.45	0.90
0.04	0.06	60	1	5	2400	3600	0.34	0.17	1.70	0.85
0.04	0.06	60	3	5	2400	3600	0.33	0.13	1.65	0.65
0.04	0.06	60	5	5	2400	3600	0.16	0.07	0.80	0.35
0.04	0.06	60	7	5	2400	3600	0.08	< LOQ	0.40	-
0.04	0.06	60	10	5	2400	3600	0.06	< LOQ	0.30	-
0.04	0.06	60	15	5	2400	3600	< LOQ	< LOQ	0.25	-

ADI – Acceptable Daily Intake, MPI – Maximum Permissible Intake, TMRC – Theoretical Maximum Residue Concentration

MPI = ADI x Average body weight x 1000, TMRC = Daily consumption rate x Average residue

1, 3, 5, 7, 10 and 15 days after spraying were 2.45, 1.7, 1.65, 0.80, 0.40, 0.30 and 0.25 μg person^{-1} day^{-1} respectively. The MPI value was found as above the TMRC values and hence the risk associated with beta cyfluthrin on chilli was considered as zero. The chilli fruits were said to be safe for consumption from the day of spraying itself.

Imidacloprid

The ADI of imidacloprid is 0.06 mg kg^{-1} bw day^{-1} and the MPI calculated was 3600 μg person^{-1} day^{-1}. The insecticide reached below LOQ at seventh day after spraying onwards. The TMRC values calculated for imidacloprid on chilli fruits were 0.90, 0.85, 0.65 and 0.35 μg person^{-1} day^{-1} during 0, 1, 3 and 5 days after spraying respectively. The calculated TMRC values are too below the MPI values and hence the risk associated with spraying of imidacloprid on chilli was considered as zero and the produce was safe for human consumption.

4.6.2 Fipronil 40% + Imidacloprid 40% WG

The risk assessment of of Fipronil 40% + Imidacloprid 40% WG is shown in Table 23.

Fipronil

The ADI of fipronil is 0.0002 mg kg^{-1} bw day^{-1}. The MPI value calculated was 12 μg person^{-1} day^{-1}. The insecticide reached below LOQ on the day of spraying itself. The TMRC value calculated for fipronl in chilli is zero from the 0th day of spraying. Since the TMRC value was less than the MPI value, the product was safe for consumption.

Imidacloprid

The ADI of imidacloprid is 0.06 mg kg^{-1} bw day^{-1}. The MPI value calculated was 3600 μg person^{-1} day^{-1}. The insecticide reached below LOQ on third day after spraying. The TMRC value calculated for imidacloprid in chilli fruits were 0.45 and 0.30 μg person^{-1} day^{-1} on 0 and 1 day after spraying respectively. The calculated TMRC values are too below the MPI values and

Table. 23 Risk assessment of fipronil 40% + imidacloprid 40% WG in chilli fruits

ADI (mg kg^{-1} bw d^{-1})		Average body weight (kg)	Interval (Days)	Daily Consumption rate (g day^{-1})	MPI (µg $person^{-1}$ day^{-1})		Average residue (µg g^{-1})		TMRC (µg $person^{-1}$ day^{-1})	
Fipronil	Imidacloprid				Fipronil	Imidacloprid	Fipronil	Imidacloprid	Fipronil	Imidacloprid
0.0002	0.06	60	0	5	12	3600	< LOQ	0.09	-	0.45
0.0002	0.06	60	1	5	12	3600	< LOQ	0.06	-	0.30
0.0002	0.06	60	3	5	12	3600	< LOQ	< LOQ	-	-

ADI – Acceptable Daily Intake, MPI – Maximum Permissible Intake, TMRC – Theoretical Maximum Residue Concentration

MPI = ADI x Average body weight x 1000, TMRC = Daily consumption rate x Average residue

hence the risk associated with spraying of imidacloprid on chilli was considered as zero and the produce was safe for human consumption.

4.6.3 Spiromesifen 22.9% SC as Single Insecticide

The ADI of spiromesifen is 0.03 mg kg^{-1} bw day^{-1}. The MPI value calculated as 1800 µg $person^{-1}$ day^{-1}. The insecticide reached BDL on 15 day after spraying. The TMRC value calculated for spiromesifen was 6.10, 3.40, 2.90, 2.65, 1.10 and 1.35 µg $person^{-1}$ day^{-1}on 0, 1, 3, 5, 7 and 10 days after spraying respectively. The calculated TMRC values are too below the MPI values and hence the risk associated with spraying of spiromesifen on chilli was considered as zero and the produce was safe for human consumption (Table. 24)

4.6.4 Thiamethoxam 25 % WG as Single Insecticide

The ADI of thiamethoxam is 0.08 mg kg^{-1} bw day^{-1}. The MPI of thiamethoxam from chilli was found as 4800 µg $person^{-1}$ day^{-1}. The residues of thiamethoxam reached BDL at fifth day after spraying onwards. The calculated TMRC values were 0.85, 0.45 and 0.35 µg $person^{-1}$ day^{-1} during 0, 1 and 3 days after spraying. As the TMRC values are less than the MPI value, thiamethoxam can be considered as the insecticide with no risk on chilli. Moreover the chilli fruits were safe for human consumption on the day of spraying itself as the residues remained on the fruits were too below the MPI (Table.24)

Table. 24 Risk assessment of spiromesifen 22.9% SC and thiamethoxam 25 % WG in chilli fruits

ADI (mg kg^{-1}bw d^{-1})		Average body weight (kg)	Interval (Days)	Daily Consumption rate (g day^{-1})	MPI (µg $person^{-1}$ day^{-1})		Average residue (µg g^{-1})		TMRC (µg $person^{-1}$ day^{-1})	
Spiromesifen	Thiamethoxam				Spiromesifen	Thiamethoxam	Spiromesifen	Thiamethoxam	Spiromesifen	Thiamethoxam
0.03	0.08	60	0	5	1800	4800	0.92	0.17	6.10	0.85
0.03	0.08	60	1	5	1800	4800	0.68	0.09	3.40	0.45
0.03	0.08	60	3	5	1800	4800	0.58	0.07	2.90	0.35
0.03	0.08	60	5	5	1800	4800	0.53	< LOQ	2.65	-
0.03	0.08	60	7	5	1800	4800	0.22	< LOQ	1.10	-
0.03	0.08	60	10	5	1800	4800	0.21	< LOQ	1.05	-
0.03	0.08	60	15	5	1800	4800	< LOQ	< LOQ	-	-

ADI – Acceptable Daily Intake, MPI – Maximum Permissible Intake, TMRC – Theoretical Maximum Residue Concentration

MPI = ADI x Average body weight x 1000, TMRC = Daily consumption rate x Average residue

Discussion

5. DISCUSSION

Since independence, India has arrived a long way from being a food-deficit to a food surplus country. India has a positive trade balance in this sector, which is an important contributor to India's trade earnings. Unfortunately, Indian commodities are often facing rejections from international markets due to the lack of compliance with food safety and health standards, chiefly owing to the presence of pesticide residues. In May 2015, Saudi Arabia temporarily banned the import of Indian green chillies due to the presence of high levels of pesticide residues (Goyal *et al.,* 2017). Chilli is one of the chief spices facing rejections from foreign markets. This is evident from the frequent occurrence of pesticide residues from both green and red chilli sampled from public market (PAMSTEV, 2018).

Chilli (*Capsicum annuum* L.) is one of the major vegetable and spice crops grown in the country. A major bottle neck in the production is the infestation of pest complex in chilli with more than 293 insects and mite species debilitating the crop in the field as well as in storage. The major insect pests that attack chilli are aphids (*M. persicae* and *A.gossypii*), mites (*P. latus*) and thrips (*S. dorsalis*). To manage these sucking pests, farmers used to apply minimum of 25 to 30 rounds of pesticide sprays and this not only increases the cost of cultivation but often causes problems like resistance, resurgence of target insects and secondary pest outbreak in addition to these residues to food, groundwater, adverse effect on human health and wide spread killing of non-target organisms (Kurbett *et al.,* 2018).

Development of insecticide mixture is one of the promising options to reduce the pesticide load to the environment. It has the potential to increase the commercial lives of insecticide through their use in combinations, by complementing the bioefficacy of the individual products and simultaneously lowering their use pressure on one hand and broadening the spectrum of activity and overcoming pest resistance to individual insecticide on the other hand (Regupathy and Ramasubramanian, 2004). Insecticide mixture delay the development of resistances, since it contains different insecticides with different mode of actions. The dose requirement of combination insecticide is as lower as compared to individual single insecticide, so that it leaves less residues in the environment as well as in the crop. Moreover it reduces labour costs and controls more than one pest at a time (Das, 2014). No studies have been conducted on the bio efficacy and residue behaviour of insecticide mixtures on chilli and the present study would be a good attempt to generate some newer information on the particular area.

5.1 PRELIMINARY EVALUATION OF INSECTICIDE MIXTURES AGAINST SUCKING PEST COMPLEX IN CHILLI

A preliminary evaluation was conducted to screen seven insecticides *viz.,* thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC, beta cyfluthrin 8.91% + imidacloprid 19.81 % OD, flubendiamide 19.92% + thiacloprid 19.92 % SC, fipronil 40 % + imidacloprid 40 % WG, hand mixing of spiromesifen 22.9% SC + thiamethoxam 25 % WG (1:1), spiromesifen 22.9% SC and thiamethoxam 25 % WG for their efficacy in controlling sucking pest complex in chilli. The different sucking pests encountered were whitefly, *A. trachoides*, chilli thrips, *S. dorsalis*, chilli mite, *P. latus* and aphid, *A. gossypii*

Among seven insecticides, fipronil 40% + imidacloprid 40% WG @ 175 + 175 g ai ha^{-1} was found to be the best treatment which controls all the sucking insects as well as mite. Figure. 1 depicts the number of whiteflies, thrips, mites and aphids per leaf at 5 DAS obtained from Table 7 to 10. It caused cent per cent mortality of whiteflies, thrips, mites and aphids from seventh day after spraying onwards. This was more or less on par with beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}. Spiromesifen @ 96 g a.i $ha^{-1}$was proved to be the effective acaricide with cent per cent mortality of mites from second day after spraying.

The studies on bio efficacy of insecticide mixtures against chilli pests are so meagre. However, several research works on efficacy of insecticide mixture against pests of cotton, tea and rice are available. Patil *et al.* (2009) reported that

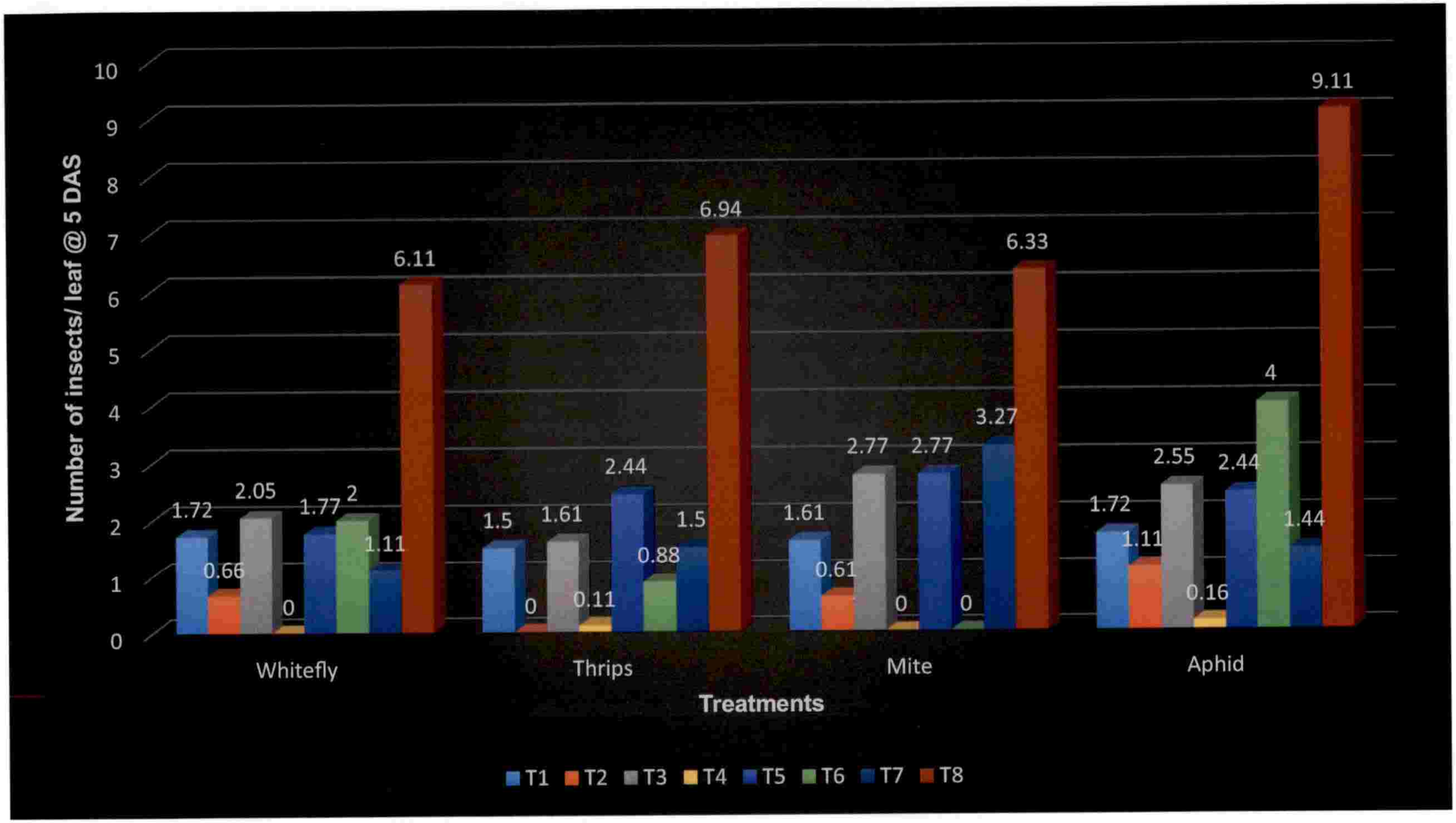


Figure.1 Population of sucking insects in chilli sprayed with different insecticide mixtures at 5 DAS

T1 - Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5 % ZC

T2 - Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD

T3 - Flubendiamide 19.92% + Thiacloprid 19.92 % SC

T4 - Fipronil 40% + Imidacloprid 40% WG

T5 - Hand mixing of Spiromesifen 22.9% SC and Thiamethoxam 25 % WG (1:1)

T6 - Spiromesifen 22.9% SC

T7 - Thiamethoxam 25 % WG

T8- Control

99a

fipronil 40% + imidacloprid 40% 80 WG @ 100 ml ha^{-1} was the best treatment in controlling aphids, thrips and whiteflies in cotton. This finding is in agreement with present study.

Fipronil 40 % + imidacloprid 40 % WG is a new combination insecticide recommended by CIBRC and it has a label claim for sugarcane white grub, *Holotrichia consanguinea* (CIBRC, 2018).

Fipronil exhibits high insecticidal activity against many insects and other arthropod pests (Tingle *et al.,* 2003). Fipronil is a phenylpyrazole compound which is well-known for disturbing the ligand-gated chloride channels from the cell membranes of insects (Bloomquist, 2003). The chloride channels are responsible with the hyperpolarization of the potential membrane, with other words, it favours the entrance in the cell of chloride ions (Mohamed *et al.,* 2004). Blockage of the GABA-gated chloride channels by fipronil reduces neuronal inhibition and leads to hyper-excitation of the central nervous system, convulsions and death. Glutamate-gated GABA chloride channels appear to be a critical target for fipronil, since these channels are only found in invertebrates, possibly explains the high selectivity of fipronil for invertebrate pests (Zhao *et al.,* 2005).

Imidacloprid is a systemic, chloro-nicotnyl insecticide used for the control of sucking insects such as fleas, aphids, whiteflies, termites, turf insects, soil insects and some beetles. It works by interfering with the transmission of stimuli in the insect nervous system causing irreversible blockage of acetylcholine receptors. These receptors are rendered incapable of receiving acetylcholine molecule and an accumulation of acetylcholine occurs, resulting in the insect's paralysis and eventual death (Girradi *et al.,* 2017). Thus the insecticide mixture fipronil + imidacloprid became the best treatment for the sucking pests of chilli.

Several studies have been conducted by using fipronil and imidacloprid as single insecticide against sucking pest complex of chilli. Various formulations of imidacloprid used as either soil drench or foliar application provide effective control of *S. dorsalis* without harming natural control agents. Imidacloprid suppresses *S. dorsalis* population for many days (Seal and Kumar 2009). Sathua *et al.* (2017) found that imidacloprid 17.8 SL reduced 82.46 per cent thrips population followed by acephate 75 SP (80.86 %). Fipronil 5 SC @ 25 ml a.i.ha^{-1} was found as a superior treatment in controlling chilli thrips, *S. dorsalis* (Patil *et al.*, 2018). Sahu and Kumar (2018) also reported that fipronil 5 SC @ 2 ml^{-1} was the best treatment for managing chilli thrips population and was statistically on par with imidacloprid 17.8 SL @ 0.2 ml l^{-1}.

Wadnerkar *et al.* (2003) reported that fipronil 5 SC and 5 EC at 100 g a.i ha^{-1} were effective against aphids, *A. gossypii* in cotton. Jadav *et al.* (2004) proved that fipronil 5 SC at 50 g a.i ha^{-1} was effective against aphid population in chilli. Shinde *et al.* (2011) concluded that imidacloprid 200 SL @ 0.004 % was most effective for the management of aphids and jassids in chilli. The effectiveness of fipronil and imidacloprid in controlling chilli aphid population was best explained by Indhumathi *et al.* (2017a), where they found that three foliar application of fipronil 200 SC @ 50 g a.i. ha^{-1} was highly effective in checking down the pest population. All these works are supporting the present study.

There was a significant reduction in the population of mite in plants treated with fipronil + imidacloprid. Manjunatha *et al.* (2000) observed that chilli plants sprayed with imidacloprid 75 WS @ 0.50 g l^{-1} reduced the population of mite, *P. latus* and lower LCI as compared to untreated control. Fipronil 5 SC @ 0.01% was found to be more effective in reducing mite population in chilli (Reddy *et al.*, 2005). The results of the present study are in line with these research findings. Halder *et al.* (2015) and Kurbett *et al.* (2018) found that fipronil 80 WG was the best treatment for controlling the population of chilli mite, *P. latus*.

The results of the present study revealed that beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} was the best treatment in managing sucking pest complex of chilli next to fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1}. There are several studies which supports the results of present study. Study conducted by Girradi *et al.* (2017) proved that the combi product Solomon (Beta cyfluthrin 65.1+Imidacloprid 27.9 g a.i ha^{-1}) @ 310 ml ha^{-1} was superior in reducing thrips (0.62 / six leaves) and whiteflies (0.26 / six leaves). The research works related to the efficacy of beta cyfluthrin 8.91% + imidacloprid 19.81 % OD against sucking pests in vegetables are so scanty. Similar results was reported by Zote *et al.* (2018) in cashew, and they noticed that beta cyfluthrin 90% + imidacloprid 210 % @ 1.5 ml 10 l^{-1} was the superior treatment for managing the cashew thrips, *S. dorsalis.*

Solomon 300 OD contains time tested beta cyfluthrin and imidacloprid in an innovative oil dispersion formulation. It is a mixture of emulsifiers and solvents that helps break oil into small droplets. It has a combination of systemic and contact properties which gives quick knockdown and anti-feeding effects proved to be a broad segment insecticide for sucking and biting pests. Beta cyfluthrin is an insecticide of the synthetic pyrethroid group having contact and stomach action. It acts on the insects' nervous system as sodium channel blocker. Rapid excitation and impairment of coordination are the first visible symptoms of intoxication in insects followed by knockdown and death.

Among the different insecticides, Spiromesifen 22.9 SC @ 96 g a.i ha^{-1} was an excellent acaricide. Present study recorded cent percent mortality of mite, *P. latus* from third day of spraying onwards. Study conducted by Kavitha *et al.* (2006) reported that spiromesifen 240 SC @ 120 g a.i ha^{-1}showed 91.70 per cent reduction in chilli mite population. The results are in agreement with the findings of Nagaraj *et al.* (2007) and Sekh *et al.* (2007) also. Study conducted by Varghese and Mathew (2013) in Kerala reported the similar results.

Spiromesifen is a novel insecticide/acaricide belonging to the new chemical class of spirocyclic phenyl-substituted tetronic acids, and it is especially active against whiteflies and tetranychid spider mite species (Bielza *et al.,* 2009). It acts on lipid synthesis by inhibiting acetyl CoA carboxylase and causes a significant decrease in total lipids (Ghanim and Ishaaya, 2011). Because of its high selectivity, good residual activity, minimal risk to pollinators and predatory mites combined with a novel mode of action make spiromesifen as an excellent new tool for many integrated pest management programs (Singh *et al.,* 2016; Kodandaram *et al.,* 2016). It works by preventing the treated mite from maintaining proper water balance and results in dessication, drying and death of mite.

Based on the results of the laboratory screening, four insecticides were selected for evaluating their efficacy at field conditions. The selected insecticides were fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1}, beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, spiromesifen 22.9 % SC @ 96 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1}.

5.2 FIELD EVALUATION OF SELECTED INSECTICIDE MIXTURES AGAINST SUCKING PESTS OF CHILLI

Results of the field evaluation of selected insecticide mixtures revealed that fipronil 40 % + imidacloprid 40 % WG @ 175 + 175 g a.i ha^{-1} showed superiority over other mixtures. Figure.2 represents the number of whiteflies, thrips, mites and aphids per leaf at 7 DAS obtained from Table 11 to 14. A lower number of whiteflies, thrips, mites and aphids were observed on sprayed plants.

Saini *et al.* (2016) and Sangamithra *et al.* (2018) reported that imidacloprid 17.8 SL @ 125 g a.i ha^{-1} was the superior insecticide for reducing the population of chilli whitefly, *B. tabaci* followed by fipronil 5 % SC @ 800 ml ha^{-1} and these two treatments were statistically on par to each other and the findings were in accordance with the results of the present study.

Halder *et al.* (2015), Samota *et al.* (2017) and Khanzadal *et al.* (2018) found out that fipronil and imidacloprid were superior in checking the population of thrips, *S. dorsalis* and aphids, *A.gossypii* in chilli as single insecticides.

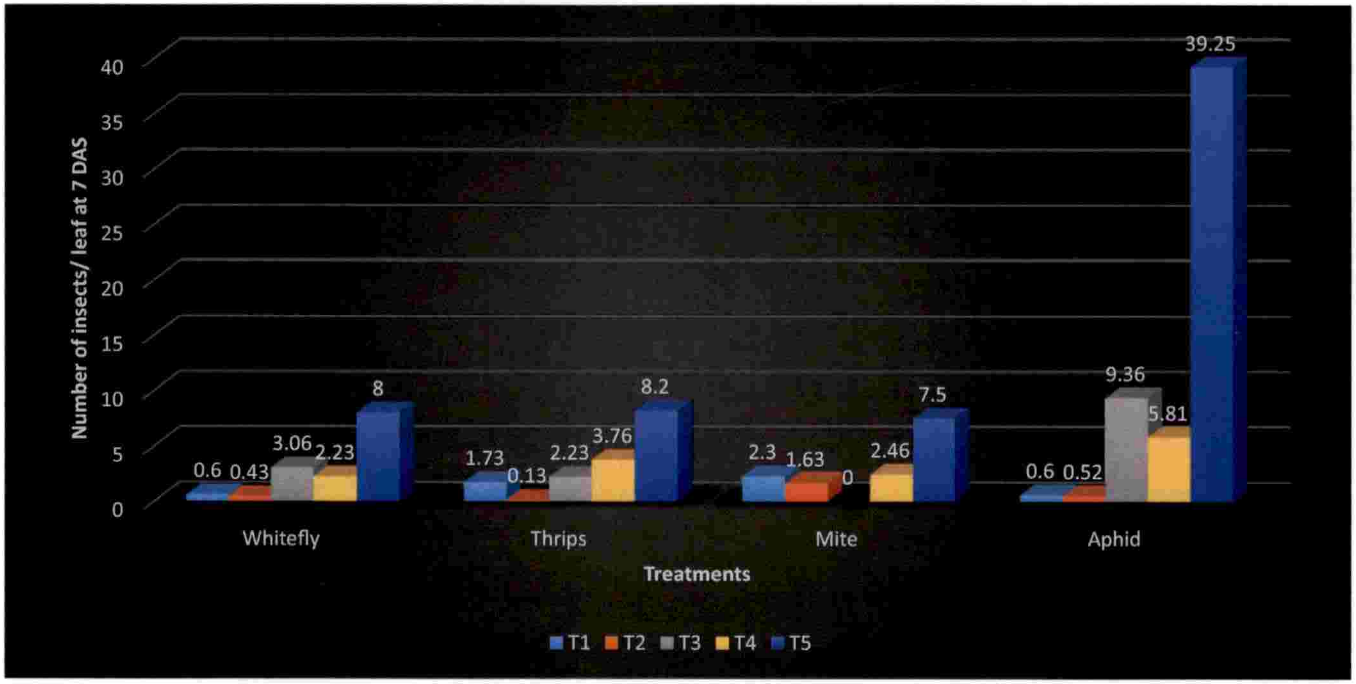


Figure.2 Population of sucking insects in chilli sprayed with different insecticide mixtures under field conditions at 7 DAS

T1 – Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD

T2 - Fipronil 40% + Imidacloprid 40% WG

T3 - Spiromesifen 22.9% SC

T4 - Thiamethoxam 25 % WG

T5 – Untreated control

5.3 SAFETY OF INSECTICIDE MIXTURES AGAINST COCCINELLIDS AND SPIDERS

Higher population of coccinellids were observed in spiromesifen 22.9 % SC 96 g a.i ha^{-1} at 1, 3, 5, 7, 10 and 15 days after spraying and it was relatively similar to coccinellids seen in untreated plants. Figure. 3 is representing the number of coccinellids and spiders per 6 plants at 15 DAS obtained from Table 16 and 17. Among different insecticide mixtures, the plants treated with fipronil 40% + imidacloprid 40% WG @ 175 g a.i ha^{-1} showed a higher average population of coccinellids followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 33 g a.i ha^{-1}whereas thiamethoxam found as more toxic towards coccinellids.

The reduction in population of spiders followed the similar pattern as that of coccinellds. Among the five insecticide mixtures/ insecticides tested, spiromesifen 22.9 % SC was found as the safest insecticide towards spiders as it maintained its higher number even after 15 days of spraying and it is relatively similar to the population of spiders seen in untreated control. All the insecticide treated plants, except spiromesifen 22.9 SC maintained no spiders after 7 days of spraying and there was gradual increase in the population of spiders in different insecticide treated plants after 7 days of spraying.

In Kerala, Varghese and Mathew (2013) reported that spiromesifen was the safest insecticide against predatory mite, coccinellid beetles, spiders and neutral insects and the results were in line with present findings. Roy and Sarkar (2017) also found that spiromesifen 22.9 SC @ 90 g a.i ha^{-1} was the safest insecto-acaricide against predatory fauna in chilli ecosystems. It caused only 4.5, 4.2 and 5.3 per cent reduction in *C. septempunctata*, *C. sexmaculata* and spider complex respectively after 15 days of treatment.

The mean population of coccinellids was found to be more in the untreated check followed by fipronil 200 SC @ 30 and 40 g a.i ha^{-1} in the first, second and third day after foliar application in chilli ecosystem. The lower dose of fipronil

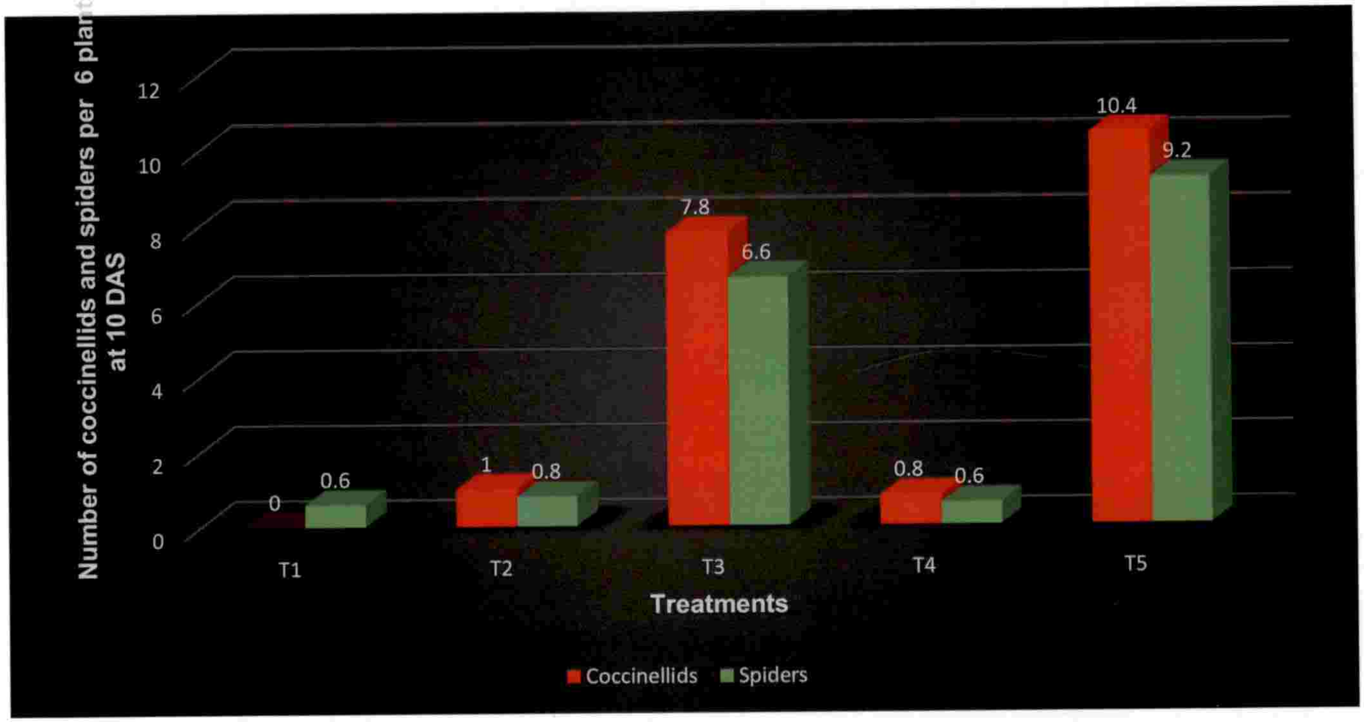


Figure. 3. Number of coccinellids and spiders per 6 plants in chilli sprayed with different insecticide mixtures at 10 DAS

T1 – Beta cyfluthrin 8.91% + Imidacloprid 19.81 % OD

T2 - Fipronil 40% + Imidacloprid 40% WG

T3 - Spiromesifen 22.9% SC

T4 - Thiamethoxam 25 % WG

T5 – Untreated control

200 SC at 30 g a.i ha^{-1} recorded the mean population of coccinellids as 8.91per ten plants, which was next to the untreated check (11.90 per ten plants) (Indhumathi *et al.,* 2017 b). These recent studies thus confirm our findings on the relative safe nature of fipronil against coccinellids and spiders associated with chilli ecosystems.

However, Jaafar *et al.* (2013) found that fipronil 240 SC at 150 g a.i ha^{-1} was unsafe to spiders and coccinellids seen in rice ecosystem. Fipronil 5 SC @ 0.01 % was very toxic to predatory coccinellids, *C. septempunctata* in cabbage (Sharma *et al.,* 2017). All these findings are contradictory to present results.

Imidacloprid, a neurotoxin belonging to neonicotinoid affects the behaviour and performance of natural enemies by affecting their fecundity, egg hatching, developmental time, growth rate, locomotion, survival rate and causing mortality of various coccinellids (Desneux *et al.,* 2007). Zaini (2017) found that imidacloprid 17.8 % SL caused cent per cent mortality of spiders after ten days of spraying in brinjal. All these findings, concluded that imidacloprid is a potent toxicant against coccinellids and spiders. But when it comes in combination with fipronil the same toxicity towards the natural enemies is gets reduced, because in combination the dose of each insecticide is lower than in individual spray and it is evident from this experiment. The same situation was explained by Girradi *et al.* (2017) and they found that the coccinellid population in chilli was higher (4.00 per plant) when it was sprayed with beta cyfluthrin 90 + imidacloprid 210 OD @ 15.3 + 35.7 g a.i ha^{-1}. But the population was lower in both beta cyfluthrin 25 SC @ 28 g a.i ha^{-1} (2.40 per plant) and imidacloprid 200 SL@ 65.2 g a.i ha^{-1} (2.00 per plant) sprayed plants.

5.4 PERSISTENCE AND DISSIPATION OF INSECTICIDE RESIDUES ON CHILLI

Though pesticides are inevitable for controlling pests, they are inherently poisonous molecules having the potential to contaminate the environment and food chain, if used indiscriminately. Among the different pesticides used for pest management in chilli, the systemic compounds get absorbed and translocated throughout the plant system including the edible portion. These residues may persist even at the time of harvest by leaving toxic residues in the harvested produce. There are reports on the detection of pesticide residues even in chilli and chilli product samples collected from retail outlets (Rao, 2005). Dissipation studies of insecticides on chilli is more important to ensure the safety of product for human consumption.

In the present study, the effective mixture of fipronil and imidacloprid dissipated below LOQ in 0 and 3 days respectively. The studies on dissipation of fipronil + imidacloprid on chilli are scanty. However, Aman *et al.* (2013) reported that, fipronil 5 SC @ 50 g a.i ha^{-1} left no residues after 20 days of spraying. The studies on the residues of imidacloprid 12 % @ 1000 ml ha^{-1} revealed that more than 65 % of residues were dissipated within 3 days of spraying and it reached below LOQ of 0.03 mg kg^{-1}after 5 days of spraying (Chahil *et al.,* 2014). Contradictory to the present study, Xavier *et al.* (2014) reported that fipronil 80 WG at 40 g a.i ha^{-1} was dissipated to below LOQ of 0.01 mg kg^{-1} at 21 days after spraying.

The mixture of beta cyfluthrin and imidacloprid took 15 and 7 days respectively to reach below LOQ. Contradictory to the present study, Sahoo *et al.* (2009) reported that a combination formulation of solomon 300 OD (betacyfluthrin 9% + imidacloprid 21 %) @ 120 g a.i ha^{-1} dissipated to below LOQ of 0.01 mg kg^{-1} after 5 days for beta cyfluthrin and 7 days for imidacloprid on okra plant. Similar results were observed by Mandal *et al.* (2009) on brinjal also.

In the present study spiromesifen 22.9 SC @ 96 g a.i ha^{-1} had dissipated and reached to below LOQ at 15 days after spraying. Similar results was observed by Sharma *et al.* (2007) and Varghese (2011). The persistence of pesticides and their residues in commodity at harvest / food depends on several factors such as nature and amount of pesticide used, number of application, type of crop, method of application, weather conditions, interval between application and harvest. In addition, the residues also occur as a result of circumstances not designed to protect the crop, and soil containing residues of persistence pesticides (Sharma, 2015).

Dietary intake of vegetables and fruits acts as a predominant route of pesticides to human. The route of pesticides through dietary intake is much higher than other means such as air and drinking water (Claeys *et al.*, 2011). Hence there is a necessity to assess the potential risk of the insecticides on human health. Therefore risk assessment studies were conducted by utilizing the data generated through dissipation studies of effective insecticide mixtures/ insecticides. The result revealed that all insecticide mixtures/insecticide *viz.*, fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1}, betacyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, spiromesifen 22.9% SC @ 96 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} does not create any health problems to consumers.

Sanyal *et al.* (2008) studied the risk assessment of acetamiprid on chilli by comparing TMRC (Theoretical Maximum Residue Concentration) and it was found that MPI (Maximum Permissible Intake) was higher than TMRC and consumption of acetamiprid treated chilli is safe for consumption. Bhardwaj *et al.* (2012) reported that consumption of fipronil treated cabbage (at recommended dose) was safe even on the day of spraying. Study conducted by Paramasivam *et al.* (2014) reported that gherkin fruit was safe for the consumption even on the day of spraying of fipronil. The mere presence of pesticide residues in food commodities cannot consider as risk unless it is proved through risk assessment studies. Contradictory to the present study, Padmanabhan (2018) reported that consumption of fipronil treated cabbage and cauliflower can cause deleterious health impact on human.

In recent years the development and use of combination products of insecticides is on the rise, and the products with neonicotinoid and synthetic pyrethroid/pyrrole combinations have become very popular in sucking pest management of vegetables including chilli. The product successfully target different groups of insects, resulting in optimum control of insect population due to their varied mode of actions. The advantages of insecticide mixtures, is that they resulted in reduced number of insecticide applications, since they target more than one type of insect pests at a given point of time.

The effective insecticide mixture for the management of sucking pest complex in chilli in the present study is fipronil + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} and beta cyfluthrin 8.91 % + imidacloprid 19.81 % @ 15.75 + 36.75 g a.i ha^{-1} OD. Risk assessment studies also revealed their safety to human consumption. However a more detailed study is needed in the metabolism of insecticide mixture in plant, animal tissues and soil. More over the study related to toxicity of metabolites of insecticide mixtures is seeking more attention in future.

Summary

6. SUMMARY

Chilli (*Capsicum annuum* L.) is one of the major vegetable and spice crops grown in the country. India being the largest producer of the chilli in world, but the productivity is lower. Chilli is a crop subjected to scheduled application of insecticides and acaricides. The pesticidal sprays have become a threat to chilli ecosystem causing problems like presence of pesticide residues, environmental pollution, pest resurgence, secondary pest out-break, killing of non-target organisms. Pesticide residues in chilli are of great concern from the point of view of domestic consumption and export as well. The risk of using chemical insecticides in the management strategies can be reduced by incorporating pesticide mixture in the spray schedule. However studies on the bio efficacy and residue behaviour of insecticide mixtures on chilli are scanty and the present study would be a good attempt to generate some newer information on the particular area. The results obtained are summarized here under

- Sucking pests *viz.,* whiteflies, *A. trachoides*, chilli thrips, *S. dorsalis*, chilli mite, *P. latus* and aphids, *A. gossypii* were recorded during experiment.
- Results of the laboratory screening revealed that fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} was the best treatment in managing all sucking pests of chilli with cent per cent mortality of whiteflies, thrips, mites and aphids on seventh day after spraying. This was followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1}. Spraying of spiromesifen 22.9 SC @ 96 g a.i ha^{-1} resulted in cent per cent mortality in mite population from second day after application.
- Among four effective insecticide mixtures / insecticides selected from laboratory screening *viz.,* fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1}, beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, spiromesifen 22.9% SC @

96 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1}, fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} was found as effective treatment against whiteflies, *A. trachoides* followed by beta cyfluthrin 8.91 % + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} under field conditions.

- The results of the studies against management of chilli thrips, *S. dorsalis* using insecticide mixtures revealed that less number of thrips was observed in plants treated with fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and spiromesifen 22.9 SC @ 96 g a.i ha^{-1} against 8.92 thrips $leaf^{-1}$ in control plants after 15 days of spraying.
- Studies on the bioefficacy of insecticide mixtures against chilli mite, *P. latus* revealed that, the treatment spiromesifen 22.9% SC @ 96 g a.i ha^{-1} showed superiority over other treatments and no mite was observed on plants treated with spiromesifen from seventh day after spraying followed by fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} (1.63 mites $leaf^{-1}$) and beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.30 mites $leaf^{-1}$).
- In the management of aphids, *A. gossypii* , less number was observed in the treatment fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} (0.52 aphids $leaf^{-1}$) followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (0.60) after seven days of spraying.
- Among the four effective insecticides mixtures / insecticide, spiromesifen 22.9 SC @ 96 g a.i ha^{-1} was found to be safe to coccinellifds and spiders. The plants treated with spiromesifen 22.9 SC maintained 7.80 and 6.60 spiders per 6 plants after 15 days of spraying against 10.40 and 9.20 in control plants respectively.

- Studies on dissipation / persistence of four effective insecticide mixtures / insecticides revealed that fipronil 40% + imidacloprid 40% WG in which the single insecticide was dissipated to below LOQ within 1 and 3 days after spraying respectively. Beta cyfluthrin and imidacloprid in the mixture beta cyfluthrin 8.91% + imidacloprid 19.81 % OD dissipated within fifteen and seven days respectively.
- The risk assessment studies by using ADI, MPI and TMRC values proved that all effective insecticide mixtures / insecticide do not pose any risk to the consumers.
- The results of the present study revealed that spraying of fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} and beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} could effectively manage sucking pest complex in chilli with minimal risk to end users.

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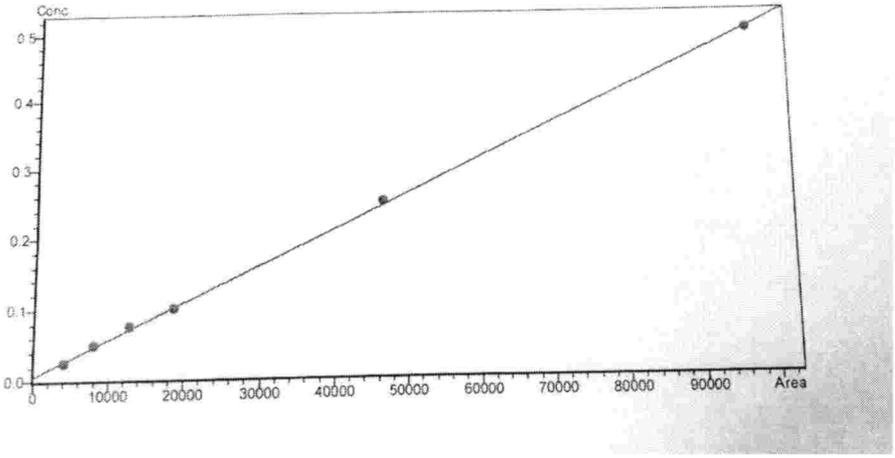
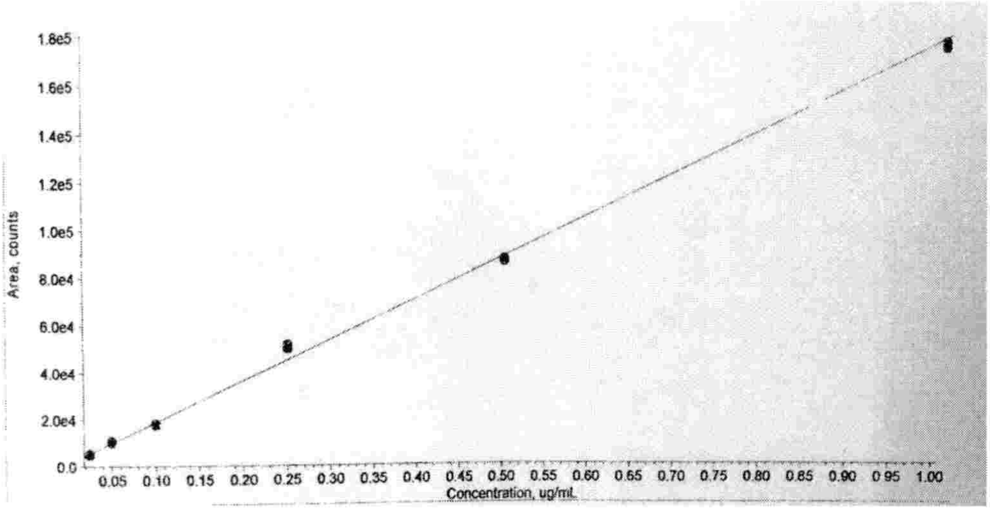
Appendices

APPENDIX I

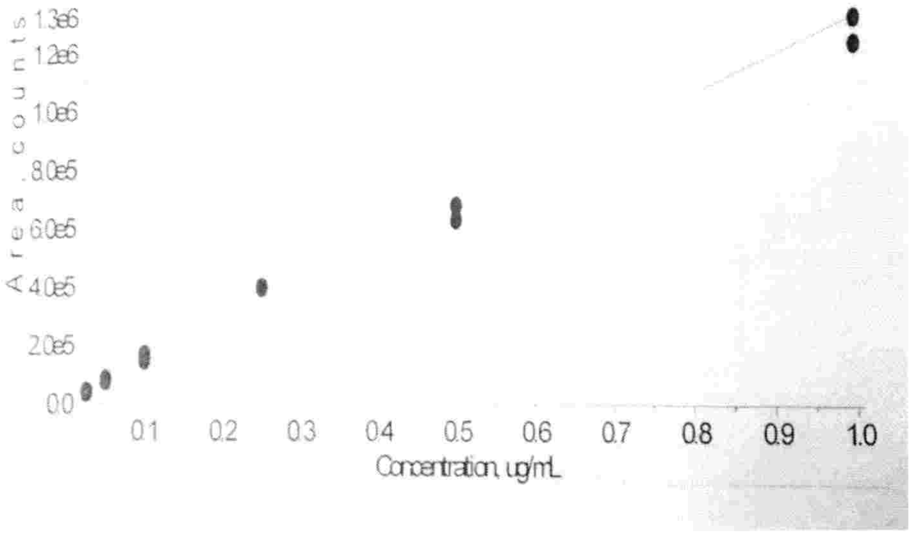


Calibration curve of beta cyfluthrin



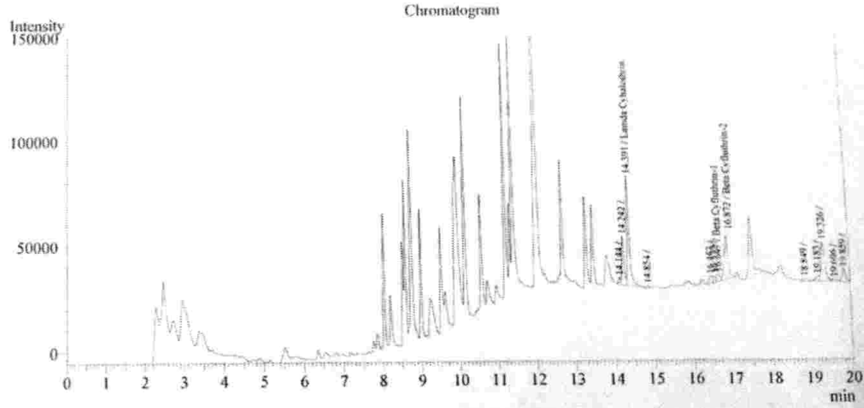
Calibration curve of fipronil

APPENDIX II



Calibration curve of spiromesifen

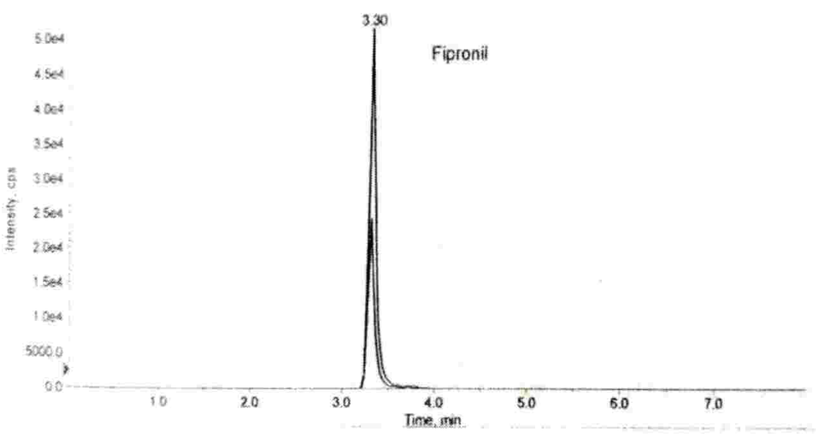
APPENDIX III



Quantitative Results - Channel 1

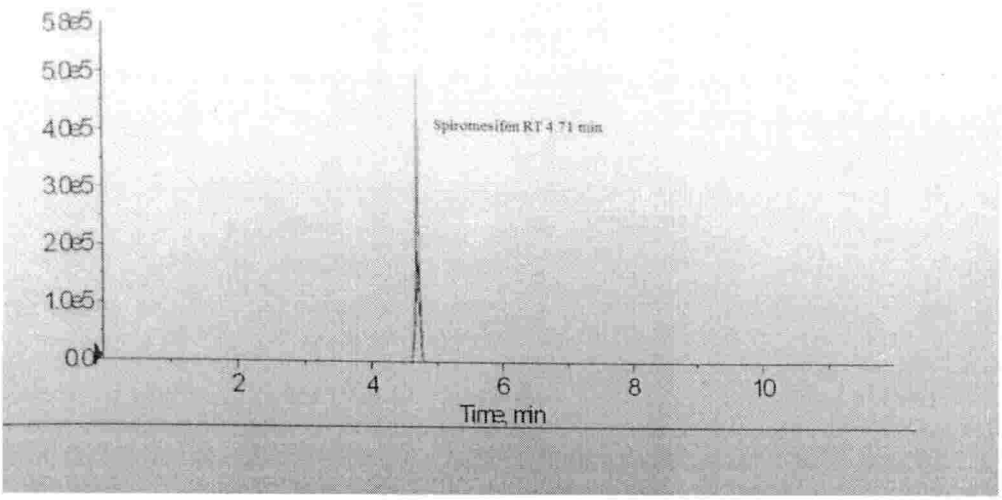
ID#	Name	Ret.Time	Area	Height	Conc.	Units
1	Lamda Cyhalothrin	14.391	206417	51833	0.052	ppm
2	Beta Cyfluthrin-1	16.647	19695	3269	0.061	ppm
3	Beta Cyfluthrin-2	16.872	130143	20271	0.052	ppm

GC MS/MS chromatogram of beta cyfluthrin



LC MS/MS chromatogram of fipronil

APPENDIX IV



LC MS/MS chromatogram of spiromesifen

INSECTICIDE MIXTURES FOR THE MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI

by

ANJU VISWANATHAN K

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Abstract of the thesis
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ABSTRACT

A study on "Insecticide mixtures for the management of sucking pest complex in chilli" was undertaken at College of Agriculture, Vellayani and farmers field at Kalliyoor during 2018 October to 2019 January. The objectives were to evaluate the efficacy of insecticide mixtures against sucking pest complex in chilli and to study the pesticide residues in chilli fruits. Major pests recorded during the study include whitefly, *Aleurothrixus trachoides* Back, thrips, *Scirtothrips dorsalis* Hoods, mite, *Polyphagotarsonemus latus* Banks and aphid, *Aphis gossypii* Glover.

The laboratory experiment was laid out in CRD to study the efficacy of insecticide mixtures *viz.,* thiamethoxam 12.6 % + lambda cyhalothrin 9.5 % ZC @ 33 + 15.75 g a.i ha^{-1}, beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, flubendiamide 19.92% + thiacloprid 19.92 % SC @ 48 + 48 g a.i ha^{-1}, fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1}, spiromesifen 22.9% SC + thiamethoxam 25 % WG (hand mixed) (1:1) @ 96 + 50 g a.i ha^{-1} along with two positive controls T6- spiromesifen 22.9% SC @ 96 g a.i $ha^{-1}$and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} against pests of chilli.

Results of the laboratory screening revealed that fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} was the effective treatment in managing all sucking pests, in which whiteflies, thrips, mites and aphids were not present on seventh day after spraying. This was followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1}. No mite population was observed in spiromesifen 22.9 SC @ 96 g a.i ha^{-1} treated plants from second day after application. The insecticide mixtures / insecticides selected for the field studies were fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1}, beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}, spiromesifen 22.9% SC @ 96 g a.i ha^{-1} and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} by considering their effectiveness in managing sucking pests under laboratory conditions.

The results of field evaluation revealed that less incidence of whiteflies was observed on fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} (0.43 leaf^{-1}) treated plants on seventh day after spraying followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}(0.60 leaf^{-1}) and thiamethoxam 25 % WG @ 50 g a.i ha^{-1} (2.23 leaf^{-1}). No population of thrips was observed in plants treated with fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} on tenth day after spraying followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}(1.30 leaf^{-1}). Spiromesifen 22.9% SC @ 96 g a.i ha^{-1} showed superiority over other treatments, in checking the population of mites, *P. latus* and no mites were observed on plants treated with spiromesifen 22.9% SC @ 96 g a.i ha^{-1} from seventh day after spraying followed by fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} (1.63 leaf^{-1}) and beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} (2.30 leaf^{-1}). Spiromesifen 22.9% SC @ 96 g a.i ha^{-1} found to be safe to natural enemies as compared to other treatments. Number of chilli aphids, *A. gossypii* was lower in fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} (0.52 leaf^{-1}) treated plants followed by beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1}(0.60 leaf^{-1}) after seven days of spraying.

Dissipation of residues of these effective insecticides was studied by analysing the chilli fruits collected at 0, 1, 3, 5, 7, 10, 15 and 30 days after treatment and the results showed that in fipronil 40% + imidacloprid 40% WG sprayed fruit, fipronil dissipated within two hours of spraying and imidacloprid dissipated in three days. Beta cyfluthrin and imidacloprid in beta cyfluthrin 8.91% + imidacloprid 19.81 % OD mixture dissipated within fifteen and seven days respectively. The risk assessment study also proved the safety of the insecticide mixtures.

The results of the present study revealed that spraying of fipronil 40% + imidacloprid 40% WG @ 175 + 175 g a.i ha^{-1} or beta cyfluthrin 8.91% + imidacloprid 19.81 % OD @ 15.75 + 36.75 g a.i ha^{-1} could effectively manage pest complex in chilli with minimal risk to end users.