BIOEFFICACY OF NEONICOTINOID INSECTICIDES AGAINST INSECT PESTS OF OKRA (*Abelmoschus esculentus* (L.) MOENCH)

By

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(2012-11-112)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) moench)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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14-10-2014

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CERTIFICATE

Certified that this thesis entitled **"Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) Moench)"** is a record of research work done independently by **Miss. Jijisha P.K.** under my guidance and supervision and that it has not previously formed for the basis for the award of any degree, diploma, fellowship or associated to her.

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INTRODUCTION

1. INTRODUCTION

Synthetic pesticides constitute an essential component in modern agriculture. About 13- 14 per cent of total pesticides used in India are consumed in vegetable crops only.

Among the synthetic insecticides, neonicotinoids represent a novel and distinct chemical class of insecticides with remarkable chemical and biological properties and low application rates. In recent years, neonicotinoid insecticides have emerged as the fastest growing class of insecticides in modern crop protection, with widespread use against a broad spectrum of sucking and certain chewing pests. As potent agonists, they act selectively on insect nicotinic acetylcholine receptors (nAChRs), their molecular target site. The discovery of neonicotinoids can be considered as a milestone in insecticide research and greatly facilitates the understanding of functional properties of the insect nAChRs.

The neonicotinoid insecticides have a high degree of versatility, not seen to the same extent in other chemical classes. Most of them can be used as foliar sprays, seed treatments and via soil application. Approximately 60 per cent of all neonicotinoid applications are soil/seed treatments and most spray applications are especially targeted against pests attacking crops such as cereals, corn, rice, vegetables, sugar beet, potatoes, cotton and others (Epperlein and Schmidt, 2001). Depending on the application method and timing, non target organisms are not affected by neonicotinoids (Epperlein and Schmidt, 2001). The extraordinary spectrum of efficacy together with full exploitation of the nAChR, plant systemicity, long-lasting effect, versatile uses and applications has contributed to the unique success of this chemical class (Elbert *et al.,* 2008). Hence they can very well be fitted in integrated pest management (IPM) systems.

The biological activity and agricultural uses of neonicotinoid insecticides are enormous and due to their unique physicochemical properties, neonicotinoids have been used in a variety of crops. The agricultural uses include control of aphids (*Aphis gossypii* Glover, *Myzus persicae* Gennadius, *Phorodon humilii* Wiki, *Rhopalosiphum padi* L.) on vegetables, sugar beet, cotton, pome fruit, cereals, and tobacco; leafhoppers and planthoppers (*Nephotettix cincticeps* (Uhler)), *Nilaparvata lugens* (Stal.) on rice; beetles on potatoes (*Leptinotarsa decemlineata* (Say)); water weevil on rice (*Lissorhoptrus oryzophilus*

Kuschel); whiteflies (*Bemisia tabaci* Gennadius, *Trialeurodes vaporarium* (Westwood)) and thrips (*Thrips tabaci* Linderman) on vegetables, cotton and citrus; micro-Lepidoptera (*Cydia pomonella* (L.), *Phyllocnistis citrella* Stainton) on pome fruits and citrus and wireworms (*Agrotis* spp.) on sugar beet.

Thiamethoxam and imidacloprid are two important systemic neonicotinoids for seed, foliar and soil applications against a variety of pests such as leafhoppers, aphids, whiteflies, thrips, beetles, bugs and borers in many crops like cotton, vegetables, corm, tubers, fruits etc. (Roberts and Hutson, 1999).

One of the major bottlenecks in the successful production of okra is the damage caused by early season sucking pests and fruit borers. Among the sucking pests, okra jassids (*Amrasca biguttula biguttulla* Ishida), aphids (*Aphis gossypii* Glover) and white flies (*B. tabaci*) are of major importance causing heavy losses. In addition to the loss caused due to direct feeding, white fly transmits yellow vein mosaic virus disease of okra (Borad *et al.*, 1993). The shoot and fruit borers, *Earias vittella* (Fabricius), *E. insulana* (Boisduval) are also important restraining factors in okra cultivation (Rahman, 1983; Prasad *et al.*, 1993; Mandal *et al.,* 2006). These pests infest the crop throughout the vegetative as well as reproductive stages and cause serious yield reduction in okra.

To protect the okra crop from the insect pests, various insecticides from different chemical classes are being applied at regular intervals by the farmers. Insecticidal sprays, the common practice for managing insect pests at early stages of crop growth is rather ineffective due to the inadequate coverage and limited efficacy of insecticide residue in the expanding leaves (Nault *et al.,* 2004). To reduce the problems associated with insecticide usage in crop protection, alternative methods of pest suppression are being tested in different parts of the world. In recent years, seed treatment with insecticides has been proved to be an effective method for the control of crop pests. Seed treatment dramatically reduces the usage of insecticides and has been advocated as an alternative to spray and granular applications. Also, it ensures the presence of active ingredients right from the seedling stage, when the plant is more vulnerable to sucking pests, to the reproductive stage and reduces the harmful effects as well on the non-target organisms.

In okra, the bioefficacy of commonly used systemic insecticides from older chemical classes is found to be getting reduced because of their continuous and indiscriminate usage. Therefore, it is imperative to identify alternative effective insecticides with low dosages and safer methods of application so as to reduce the insecticide load in the ecosystem together with managing the pests successfully in okra. Under such situations, insecticides from a newer group, neonicotinoids as seed treatment/ dresser emerged as most promising with low cost, selective, less polluting and least interference in the natural equilibrium. Seed dressing and spray formulations from this group have been widely accepted. Among these, imidacloprid and thiamethoxam have been found promising against a variety of pests such as aphids, whiteflies, thrips, beetles, leaf hoppers, bugs and borers in vegetables and other crops. In this context, two important neonicotinoid insecticides *viz.,* thiamethoxam and imidacloprid- as seed treatment, foliar spraying and a combination of seed treatment followed by a foliar spraying- were selected and undertaken the present study entitled "Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) Moench)" with the following objectives.

1. Evaluation of biological efficiency of thiamethoxam and imidacloprid by three methods of application *viz.,* seed dressing, foliar treatment and a combined application of seed treatment followed by foliar spraying against the major insect pests of okra.
2. Safety of thiamethoxam and imidacloprid to natural enemies in okra ecosystem
3. Influence of thiamethoxam and imidacloprid on plant growth parameters of okra
4. Persistence of thiamethoxam and imidacloprid residues in okra fruits

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The literature pertaining to the present study "Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) Moench)" is reviewed and presented in this chapter.

Neonicotinoids are the most important chemical class of insecticides introduced in to the global market after the synthetic pyrethroids. The outstanding development of neonicotinoid insecticides for modern crop protection, consumer/ professional products and animal health markets between 1990 and today reflects the enormous importance of this chemical class (Jeschke *et al.*, 2011).

Neonicotinoids were developed in 1980s and the first commercially available compound, imidacloprid, has been in use since the early 1990s (Kollmeyer *et al.* 1999). They are nicotinic acetylcholine receptor (nAChR) - one of the insecticide molecular target sites of growing importance, playing a central role in the mediation of fast excitatory synaptic transmission in the insect central nervous system (CNS) - agonists binding strongly to nAChR and causing nervous stimulation at low concentrations, but receptor blockage, paralysis and death at higher concentrations. Neonicotinoids bind more strongly to insect nAChRs than to those of vertebrates and so they are selectively more toxic to insects (Tomizawa and Casida, 2003).

Seven neonicotinoid insecticides launched in the market between 1991 and 2002 include the three cyclic compounds - neonicotinoids with five membered ring systems such as imidacloprid and thiacloprid and the six membered neonicotinoid- thiamethoxam, and the four non - cyclic compounds - nitepyram acetamiprid, clothianidin and dinotefuran. According to the pharmacophore, the neonicotinoid insecticides can be classified into three chemical groups *viz.,* N-nitroguanidines (imidacloprid, thiamethoxam, clothianidin and dinotefuran), nitromethylenes (nitenpyram) and N-cyanoamidines (acetamiprid and thiacloprid). Neonicotinoids are registered globally in more than 120 countries and they are among the most effective insecticides for the control of sucking pests such as aphids, whiteflies, leaf and planthoppers, thrips, some micro-lepidoptera, and a number of coleopteran pests (Jeschke *et al.*, 2011).

Neonicotinoids are water soluble and are readily absorbed by plants via roots or leaves and are transported throughout the tissues of the plant. This provides many advantages in pest control, for they protect all parts of the plant; for example, they are effective against boring insects and root - feeding insects, both of which cannot easily be controlled using foliar sprays of non - systemic compounds. Concentrations in plant tissues and sap between 5 and 10 ppb (parts per billion) are generally regarded as sufficient to provide protection against insect pests (Castle *et al.*, 2005; Byrne and Toscano, 2006).

The wide spread adoption of neonicotinoids is due to their flexibility of use, for they can be applied in many ways. They are commonly used as foliar sprays on horticultural crops such as soft fruits and on some arable crops such as soya and also for garden use as a spray on flowers and vegetables. They are used in bait formulations for domestic use against cockroaches and ants and also as granular formulations for the treatment of pasture and amenity grasslands against soil - dwelling insect pests. They can be applied as a soil drench or in irrigation water to defend perennial crops such as vines and they can be injected into timber to combat termites or into trees to protect them against herbivores where a single application can provide protection for several years. They are also commonly used in topical applications on pets such as dogs and cats to control external parasites (Oliver *et al,*. 2010).

Advantages of low toxicity to vertebrates, high toxicity to insects, flexible use and systemic activity led to neonicotinoids swiftly becoming among the most widely used insecticides globally. They are now used more than any other class of insecticides and comprise approximately one quarter of all insecticides used and are licensed for use in more than 120 countries with imidacloprid alone comprising 41 per cent of the global market and being the second most widely used agrochemical in the world (Jeschke *et al.*, 2011; Pollack, 2011).

In developed countries, neonicotinoids are predominantly used as seed dressings for a broad variety of crops such as oilseed rape, sunflower, cereals, beets and potatoes (primarily imidacloprid, clothianidin and thiamethoxam). Globally, 60 per cent of neonicotinoids are used in this way. One attraction of seed dressings is that they require no action from the farmer, prophylactically protecting all parts of the crop for several months following sowing and they are also regarded as providing better targeting of the crop than spray applications. There is abundant evidence that neonicotinoids can provide effective control of a broad range of insect pests (Jeschke *et al.*, 2011). However, they may pose environmental risks (Goulson, 2013).

The two neonicotinoids namely thiamethoxam and imidacloprid which were studied as seed treatment and foliar spray - in the present investigation, have been reviewed hereunder for their bioefficacy on insect pests, impact on natural enemies and their phytotonic effects in general and particularly on okra and cotton.

2.1. Thiamethoxam

Thiamethoxam [(EZ)-3-(2-chloro-1, 3-thiazol-5-ylmethyl)-5-methyl -1, 3, 5-oxadiazian-4-ylidene (nitro) amine.] launched in 1998 by Syngenta, and marketed as Actara® for foliar and as Cruiser® for seed-treatment uses. It belongs to the sub class thianicotinyl compounds and it represents the first example of second generation neonicotinoids with a unique structure and outstanding insecticidal activity (Maienfisch *et al.,* 1999).

2.1.1. Bioefficacy of thiamethoxam on insect pests

Thiamethoxam holds registration for 115 crop uses in at least 64 countries on a wide range of crops such as vegetables, potatoes, rice, cotton, fruit, tobacco and cereals. It is the second biggest neonicotinoid in terms of sales. The pest spectrum includes all major sucking pests as well as some chewing and soil-living pests (Elbert *et al.,* 2008).

2.1.1.1. Thiamethoxam as seed treatment

2.1.1.1. a. Okra and cotton

The use of systemic neonicotinoid, thiamethoxam, has been widely adopted to prevent attack by early-season pests in cotton and other crops. Low use rates, flexible application methods, excellent efficacy and the favourable safety profile make this new insecticide well-suited for modern integrated pest management programmes in many cropping systems (Maienfisch *et al.*, 2001).

By seed treatment, thiamethoxam moved systemically within the plant and provided protection against piercing and sucking insects such as the leafhopper *Amrasca biguttula biguttula* Ishida on okra (Kumar *et al.*, 2001).

Population of sucking pests in cotton remained low up to 56 days after sowing due to seed treatment with thiamethoxam (Cruiser 70 WS) at 6 g a.i. per kg. The treatment of cotton seeds with thiamethoxam remained effective for 44 days against aphids and 45 days against leafhopper (Mathirajan and Regupathy, 2001). According to Vadodaria *et al.* (2001) seed dressing with thiamethoxam (Cruiser) 70 WS at 4.3 and 2.8 g a.i. kg^{-1} seed kept the population of leafhoppers and aphids below ETL in cotton as compared to the standard check carbosulfan 25 DS @ 50 g kg^{-1} seeds and the untreated control. The persistent toxicity of thiamethoxam 70 WS applied as seed treatment at 3.0 and 6.0 g a.i kg^{-1} against *Amrasca devastans* was found to be 42 and 44 days in cotton (Mathirajan, 2001).

Patil *et al.* (2004) tested the efficacy of thiamethoxam (Cruiser) 350 FS - a new seed dresser formulation - for sucking pest control in cotton crop at two dosages *viz.*, 2.0 and 3.0 g a.i. kg^{-1} seed. They found that Cruiser 350 FS was effective in reducing the population of leafhoppers and provided higher yield in seed cotton.

Treatment of cotton seeds with thiamethoxam 70 WS at 10 g kg^{-1} seed was reported to be effective in suppressing the serpentine leaf miner *Liriomyza trifolii* (Burgess). Although thiamethoxam 70 WS was effective up to 50 days against the leafhopper at higher dosage (10g kg^{-1}), the lower dosage (2.85 g kg^{-1}) also suppressed the population of leafhopper and thrips up to 40 days and aphids and whiteflies up to 55 and 60 days after sowing to the levels below ETL (Prasanna *et al.*, 2004).

2.1.1.1.b. Other crops

Thiamethoxam was evaluated for controlling infestations of potato leafhopper, *Empoasca fabae* (Harris) in snap bean and found that thiamethoxam at a rate of 30 g a.i./100 kg of seed controlled leafhoppers for 31 to 38 days. Additionally, as the rate of thiamethoxam increased, the duration of protection also increased (Nault *et al.*, 2004).

Wilde *et al.* (2004) reported that seed treatment with thiamethoxam 35 FS at 0.83 mL kg^{-1} was effective in reducing populations and exhibited systemic insecticidal activity against chinch bugs, flea beetle, wireworm, white grub, and southern corn leaf beetle in corn.

Insecticidal seed treatments with thiamethoxam (Cruiser®) was reported to be effective in controlling the bean leaf beetle, *Cerotoma trifurcata* (Forster) on early growth stage of snap beans *Phaseolus vulgaris* L. over multiple planting dates during 2002–2003 in Southern Minnesota, US. (Kocha *et al.*, 2005).

Thiamethoxam at 50 g a.i./100 kg provided longer control of soybean aphid *Aphis glycines* and maintained the population density below the average economic threshold (ET) of 273 aphids per plant in soybean throughout the growing season (Ragsdale *et al.*, 2007; Magalhaes *et al.*, 2009).

Cabbage plants treated with thiamethoxam (Cruiser 350 FS) at 0.5, 0.9, 1.9, 3.8, 7.5 g a.i. kg^{-1} seed was found less damaged by flea beetles, *Phyllotreta atra* (F.), and *P. nigripes* (F). There was at least a 90 per cent reduction in the per cent of damaged plants. It was also noticed that seed treatments with thiamethoxam reduced the number of plants infested with caterpillars of diamondback moth *Plutella xylostella* (L.) as compared with the untreated control (Yildirim, 2009).

Kencharaddi and Balikai (2011) reported that seed treatment with thiamethoxam 35 FS at 10 mL kg^{-1} seed and thiamethoxam 70 WS at 5 g kg^{-1} seed proved their superiority over the untreated check and controlled the sucking pests in sunflower during the early stage (45-55 days after sowing) of the crop. Seed treatment with thiamethoxam 35 FS of 30 g a.i. per 100 kg of field pea had the lowest levels of feeding damage to stipules by pea leaf weevil, *Sitona lineatus* L. (Carcamo *et al.*, 2012).

Mahmoud *et al.* (2012) suggested that Cruiser® 350 FS (thiamethoxam) at 0.75 mL kg^{-1} of wheat seeds (0.263 g a. i. kg^{-1}) as seed dressing was the best candidate for control of the green bug, *Schizaphis graminum* (Rond.).

Seed treatment with Cruiser 350 FS at 3 mL kg^{-1} seeds could effectively control aphids (*Aphis craccivora*) in faba bean *Vicia faba* L. (Ahmed *et al.*, 2013).

2.1.1.2. Thiamethoxam as foliar spray

2.1.1.2.a. Okra and cotton

Koenig *et al.* (2000) reported that thiamethoxam spray (0.023-0.047 lbs a.i.ha^{-1}) provided significant control of aphid population in cotton. Spraying of thiamethoxam 25 WG

(0.4 g/L) on okra was found to reduce the okra leaf hopper infestation and recorded the highest yield when compared to control (Kumar *et al.*, 2001). When thiamethoxam was applied as foliar treatment at 100 g a.i. ha^{-1}, it persisted for 26 days against leafhopper and aphids in cotton (Mathirajan and Raghupathy, 2001).

Newer insecticides like thiamethoxam at 25 g a.i. ha^{-1} proved significantly superior in controlling aphids and leafhoppers on okra compared to other conventional insecticides. Thiamethoxam at 25 g a.i. ha^{-1} was found to be significantly superior in controlling jassids of okra followed by dimethoate at 300 g a.i. ha^{-1} and cypermethrin at 100 g a.i. ha^{-1} (Misra, 2002). It was noticed that the nitroguanidine thiamethoxam (25 g ai/ha) was effective in controlling okra jassids by recording 77.2 -86.0 per cent reduction of jassid population even after 21 days after application when compared to control (Acharya *et al.*, 2002).

The mean number of aphid was found to be significantly low in thiamethoxam 25 WG at 150 g a.i. ha^{-1} with 0.4, 0.83 and 1.17 aphids/leaf after 2, 7 and 14 DAS respectively (Wadnekar *et al.*, 2004). Thiamethoxam 25WG (Actara) was reported to reduce the mean per cent population of whiteflies even 240 h after spraying in okra (Khattak *et al.*, 2004). Foliar treatment with thiamethoxam (Actara 25 WG) at 24 g $acre^{-1}$ was revealed to be effective against whitefly *Bemisia tabaci* in cotton (Aslam *et al.*, 2004).

Okra leafhopper population was reported to be effectively reduced by thiamethoxam spraying at 20 g a.i. ha^{-1} (Gosalwad *et al.*, 2008). Foliar treatment with Actara 25 WG at 25 g $acre^{-1}$ was proved to be highly effective in reducing the population of jassid and whitefly up to seven days after spraying in cotton (Abbas *et al.*, 2012).

Treatments with thiamethoxam (Actara 25 per cent WG) at 20 g 100 L^{-1} water as foliar applications was observed to have moderate effect on the whitefly population (mature and immature stages) in cotton (El-Naggar *et al.*, 2013).

2.1.1.3. b. Other crops

Thiamethoxam 0.005 per cent was most effective to minimize the thrips (*Scirtothrips dorsalis* Hood) population in chilli *Capsicum frutescens* and it caused 89.93 per cent reduction of population (Mandi and Senapati, 2009). Chilli thrips count and its damage was found less in thiamethoxam 25WG at 0.2 g L^{-1} and difenthiuron 25WP at 1g L^{-1} with 0.65 & 0.7 thrip /5 leaves (Nandini *et al.*, 2012).

Jasmine and Rajendran (2011) reported that thiamethoxam 25 WG @ 0.005 per cent was highly effective against the sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner (Homoptera: Aphididae) at three, seven and 15 days after spraying in sugarcane.

Actara 25WG at 131.70 g ha^{-1} significantly suppressed *Myzus persicae* population by 67.79 per cent in potato (Khan *et al.*, 2011). Thiamethoxam 25 WG at 12.5g a.i. ha^{-1}, 25 g a.i. ha^{-1} and 50 g a.i. ha^{-1} were found effective in reducing the population of flea beetle *Scelodonta strigicollis* Mots. in grapes (Kulkarni and Patil, 2012). Foliar application of thiamethoxam 25 WG (0.0075 %) was found to be effective against leaf bug *Psylla* sp. in dodi (*Leptadenia reticulata* (Retz.) (Patel *et al.*, 2012).

In a laboratory study, thiamethoxam at 0.35 mg per mL showed the highest mortality of *Aphis punicae* in pomegranate (Rouhani, 2013). Thiamethoxam (Suckgan 25 WG) was reported to be most toxic to green peach aphid, *Myzus persicae* (Sulzer) in capsicum with LC_{50} value of 4.1 ppm (Gavkare *et al.*, 2013). It was observed that thiamethoxam 25 WG (0.0125%) was effective against jassids (*Empoasca kerri* Pruthi) and whitefly (*Bemisia tabaci*) in cluster bean, *Cyamopsis tetragonoloba* (Pachundkar *et al.*, 2013).

Wakil *et al.* (2013) reported that thiamethoxam (Actara 25 WG) at a rate of 0.75 mg kg^{-1} gave greater than 65 per cent mortality of *Rhyzopertha dominica* Fabricius 14 days after application in wheat.

2.1.2. Safety of thiamethoxam towards natural enemies

Katole and Patil (2000) reported that cotton seed treatment with thiamethoxam at 4 g kg^{-1} allowed maximum oviposition of *Chrysoperla* sp. and was at par with untreated control. According to Vadodaria *et al.* (2001) seed dressing, with thiamethoxam (Cruiser) 70 WS at 4.3 and 2.8 g kg^{-1} seed, did not affect the natural enemy population in cotton. Thiamethoxam at 50 g ai ha^{-1} resulted in 25.8 per cent mortality of the spider *Oxyopes javanus* Thorell seven days after treatment of the prey with thiamethoxam in cotton (Mathirajan and Reghupathy, 2001).

Thiamethoxam 25 WG (0.2 g L^{-1}) revealed no adverse effect on the hatchability of *Chrysoperla carnea.* However, the adult emergence, adult longevity and fecundity of *C.carnea* were found to be lowest in the insecticide treated *C. carnea* in cotton (Mathirajan and Regupathy, 2002). It was observed that thiamethoxam (Actara 250 WP) at 0, 3.9, 7.8, 15.6, 31.25, 62.5, 125 and 250 mg L^{-1} affected the parasitoid *Aphelinus gossypii* and *Delphastus pusillus* emergence in cotton (Torres *et al.,* 2003). Foliar application of thiamethoxam 25 WG (0.02%) was proved less toxic to coccinellid and spider populations in okra (Tamilvel, 2004).

Jasmine and Rajendran (2011) reported that thiamethoxam 25 WG at 0.005% was relatively safe to the predator *Dipha aphidivora* Meyrick (Lepidoptera: Pyralidae) at three, seven and 15 days after spraying against the sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner.

2.1.3. Influence of thiamethoxam on plant growth parameters

Seed treatment with thiamethoxam at 10 g per kg seed increased the plant height, number of leaves, fruiting bodies without any phytotoxic effect on cotton (Prasanna, 2000). There was a significant increase in plant height, number of leaves and fruiting bodies due to thiamethoxam 70 WS seed treatment (10 g kg^{-1} seed) and foliar spray (25 g a.i. ha^{-1}) on cotton (Prasanna *et al.,* 2004).

Foliar spraying with thiamethoxam (Actara 25 WG) at 0.40 g L^{-1} revealed a phytotonic effect on the plant height at 55, 65 and 75 DAS in okra. However, no significant difference in number of leaves at 45 DAS due to foliar sprays of thiamethoxam (Actara 25 WG – 0.40g L^{-1}) was observed. Also recorded significantly less number of fruits per plant and did not show any significant difference on days to flower initiation. But the fruit length improved significantly due to foliar spraying with thiamethoxam and it recorded a higher fruit length of 14.28 cm (Praveen (2005). A maximum plant height (141.63 cm) was noticed in thiamethoxam seed treatment in okra (Verma and Kanwar, 2009).

2.1.4. Terminal residue of Thiamethoxam in fruits

According to Singh and Kulshrestha (2005) the half life of thiamethoxam in Indian tropical conditions was quite short of 1.3 days, which might be due to the rapid vegetative growth of the okra fruits. On 7th day after application the residues were below or less than the limit of detection (LOD 0.02 ppm).

Sharma and Soudhamini (2005) tested the persistence of thiamethoxam residues in okra following foliar application of thiamethoxam @ 0.2 and 0.4 g L^{-1}. The study revealed that residues of the insecticide dissipated fast to below detectable limits within 7-10 days after their last application. The residues dissipated with half lives of 1.1 to 1.5 days and the pre harvest interval calculated on the basis of respective MRL value was 1 day for the insecticide.

Soliman (2011) reported rapid degradation of residues of thiamethoxam 25 per cent WG in cowpea pods. Initial deposit was 8.96 ppm. The residue reduced to 1.37 ppm at one week after spraying. Prolonging the time of treatment to 10 and 15 days indicated negligible residues 0.06 ppm in cowpea pods.

2.2. Imidacloprid

Imidacloprid, a chloronicotinyl nitroguanidine insecticide with the IUPAC name 1-[(6-chloropyridin-3-yl) methyl]-N-nitro-4, 5-dihydroimidazol-2-amine, is the first neonicotinoid insecticide launched in 1991 by Bayer Crop Science Limited.

Following the market launch, imidacloprid gained registration for over 140 crop uses in more than 120 countries under the main brands Confidor, Admire and Gaucho for foliar and seed dressing. Its versatility allows worldwide application against sucking and many chewing insect pests on all major crops including cotton, sugar crops, oilseed rape, cereals, rice, fruit, vegetables and ornamentals.

Imidacloprid, the chloro-niconyl insecticide, is a systemic insecticide with physical/chemical properties that allow residues to move into treated plants and then throughout the plant via xylem transport and translaminar (between leaf surfaces) movement (Buchholz and Nauen, 2002). Residues of the insecticide enter the target pest by ingestion or direct contact, disrupting the insect's nervous system by binding to postsynaptic nicotinic acetylcholine receptors. The disruption of the nervous system results in modified feeding behavior, paralysis and subsequent death of the insect (Mullins, 1993). Imidacloprid is readily translocated through plant tissues following direct contact. When used as a seed treatment, the insecticide is absorbed by the seedling from the disintegrating seed coat. Imidacloprid is used for the control of sucking insects such as fleas, aphids, whiteflies, termites, turf insects, soil insects, and some beetles. It is also used to treat seeds, soil, crops and structures and also for control of flea on domestic pets (Meister, 2000).

2.2.1.1. Bioefficacy of imidacloprid as seed treatment against insect pests

2.2.1.1. a. Okra and cotton

The effectiveness of imidacloprid has been reported on okra, brinjal and chilli fruits against various insect pests (Mote *et al.,* 1994; Jarande and Dethe, 1994). It was indicated that imidacloprid 70 WS offered protection against *A. gossypii* upto 40 days in cotton when the seeds were treated at 5.0 g kg^{-1} (Nauen and Elbert, 1994). Among various doses of imidacloprid 70 WS, 10 g kg^{-1} cotton seed could check aphid and jassid population effectively upto 45 days. It was also found highly effective against cotton thrips up to 60 days after germination (Mote *et al.,* 1995).

Sharma and Karela (1996) tested the efficacy of imidacloprid 70 WS @ 5.0 g kg^{-1} as seed treatment and observed that sucking pests population in okra could be kept below ETL for more than 45 days by seed dressing. When Singh *et al.* (1996) tried imidacloprid as seed dressing at 5, 7.5 and 10 per kg cotton seed against cotton leafhopper, *A. biguttula biguttula,* it was found that all the dosages were effective against the pest upto 121 days. Cotton seed treatment with imidacloprid 70 WS even at lower dose of 5g kg^{-1} seed was effective against jassid population upto 80 days in normal sown and upto 70 days in late sown crop (Gill *et al.,* 1996).

According to Sreelatha and Divakar (1997) seed treatment with imidacloprid at 7.5 g per kg okra seed effectively controlled the aphids and jassids up to 35 days after germination. According to Patil *et al.* (1997) the dosage of 10 g kg^{-1} seed, was effective to leaf hopper and whitefly upto 35 days in DCH-32 and upto 40 days in NHH- 44 cotton hybrids under irrigated situation.

Imidacloprid seed treatment even at a lower dose of 3 g per kg seed was also found effective against leaf hoppers up to 61-76 days in cotton (Gupta *et al.*, 1998). It was noticed that cotton seed treatment with imidacloprid (7 g kg^{-1}) resulted in 100 per cent mortality of *Amrasca devastans* Dist. up to 26 days after sowing (Kumar and Santharam, 1999). Damage by *L. trifolii* was observed to be lower in imidacloprid seed treated (15 g kg^{-1} seed) cotton plots (Sushila, 2000). Seed treatment with imidacloprid 70 WS at 10 g kg^{-1} of bhendi seeds protected the crop from leafhoppers and aphids up to nine weeks and resulted in higher fruit yield (Sivaveerapandian, 2000).

Bhargava and Bhatnagar (2001) revealed that two formulations of imidacloprid 600 FS at the rate of 9 mL kg^{-1} and 70 WS at the rate of 10 g kg^{-1} okra seed treatment performed well against jassids and whiteflies at Jaipur (Rajasthan) and recorded higher yield in okra.

By seed treatment, imidacloprid move systemically within the plant and provide protection against piercing-sucking insects such as the leafhopper, *A. biguttula biguttula* on okra (Kumar *et al.*, 2001). Seed dressing of cotton with imidacloprid (Gaucho) 700 FS at 12 mL and 9 mL kg^{-1} and imidacloprid 70 WS at 7.5 g kg^{-1} kept the population of leafhopper and aphids below ETL than the standard check carbosulfan 25 DS @ 50 g kg^{-1} seed and the untreated control (Vadodaria *et al.*,2001). But lower concentrations of imidacloprid seed treatment were observed to be less effective (Kumar *et al.*, 2001).

Aioub *et al.* (2002) observed that imidacloprid protected cotton seedlings from sap-sucking insects (whitefly and thrips) for at least 10 weeks from the onset of seed planting, but was not able to protect cotton seedlings from the attack of both jassids and mites. Imidacloprid (Poncho 600 FS at 9 mL kg^{-1} seed) could control okra or cotton jassids upto 8 weeks after sowing (Dhandapani *et al.*, 2002).

Tamilvel (2004) reported that okra seed treatment with imidacloprid 600 FS at 10g kg^{-1} seed protected the crop from leafhoppers, whiteflies, aphids and leaf rollers upto seven weeks. Less number of aphids and leaf hoppers were recorded when cotton seeds were treated with imidacloprid at 70 WS 2 g kg^{-1} seed as compared to chemical sprays (Mallapur *et al.*, 2004).

Lal and Sinha (2005) conducted an investigation to evaluate four doses (5, 9, 18, 36 g kg^{-1}) of imidacloprid 600 FS seed treatment against insect pests of okra. Their results revealed that seed treatment with imidacloprid afforded an effective protection of okra crop against the leafhoppers and their population remained below ETL upto 86 days after sowing. Imidacloprid 70 WS at 5-10 g kg^{-1} seed was found highly effective and significantly superior to carbosulfan 25 DS @ 50 g kg^{-1} seed in controlling aphid (*Aphid gossypii*) and whiteflies in okra 2005). All the dosages of imidacloprid 70 WS *viz.*, 5, 7.5 and 10 g kg^{-1} seed provided excellent protection against leafhopper and whiteflies upto 45 days after sowing in okra and their efficiencies were significantly superior to carbosulfan at 50 g kg^{-1} of seed (Dey *et al.*, 2005).

According to Sreenivas and Nargund (2006), imidacloprid 70 WS at 5g kg^{-1} as seed dressing protected bhendi crop up to 50 days from sucking insect pests.) Significant reduction in population of aphids, leaf hoppers and thrips was recorded with cotton seed treatment with imidacloprid 70 WS at 10 g kg^{-1} seed in cotton varieties DHH-543 and LRA-5166. (Hanumantharaya, 2006; Kolhe *et al.*, 2009).

Karabhantnal *et al.* (2007) observed significantly lowest population of leaf hoppers, thrips, whitefly and aphids upto 40 days after sowing in seed treated desi (diploid) cotton cultivar DB- 3-12 (*G. herbaceum*) with imidacloprid 70 WS @ 10 g kg^{-1} seed. Seed treatment with imidacloprid recorded statistically lower leaf hopper population per plant even upto 75 days after sowing of okra (Sajjan and Praveen, 2008).

Lowest aphid population was recorded in okra plots treated with imidacloprid followed by thiamethoxam (Anitha and Nandihalli, 2009). Imidacloprid seed treatment (10g kg^{-1} seed) was found to be most effective against aphids in cotton (Kohle *et al.*, 2009; Ghosh *et al.* (2010).

Zidan (2012) conducted a study to know the impact of seed treatment on sucking pests of okra and it was revealed that imidacloprid seed treatment formulation (Gaucho) seemed to be more effective than the two thiamethoxam formulations (Cruiser and Actara). Imidacloprid seed treatment formulation exhibited excellent initial reduction of hoppers within the second week post treatment, evoking remarkably a high reduction reaching 100 per cent for hoppers when applied at the recommended rate.

2.2.1.1.b. Other crops

In brinjal, seed dressing with imidacloprid 70WS (15 g kg^{-1}) followed by seedling root dip with 0.03 per cent gave promising results against leaf hoppers (Jarande and Dethe, 1994).

Sajjan *et al.* (2009) reported that sunflower seed treatment with imidacloprid 600 FS at 10.0 ml/kg could store in polythene bag of more than 700 gauge up to eight months without significant reduction in seed quality in sunflower.

Cabbage seeds film-coated with imidacloprid (Gaucho 70 WS) at 1.8, 3.5, 7, 14, 21 g a.i. kg^{-1} seed was less damaged by flea beetles, *Phyllotreta atra* (F.) and *P. nigripes* (F.) (Coleoptera: Chrysomelidae). There was at least a 90 per cent reduction in the percentage of damaged plants. Seed treatments with imidacloprid also reduced the number of plants infested with caterpillars of diamondback moth *Plutella xylostella* (L.) as compared with the untreated control (Yildirim, 2009).

In sunflower, seed treatments with imidacloprid 600 FS at 10 mL kg^{-1} seed, and imidacloprid 70 WS @ 5 g kg^{-1} seed proved their superiority over the untreated check and controlled the sucking pests during early stage of the crop up to 45-55 days after sowing (Kencharaddi and Balikai, 2011).

Imidacloprid 600 FS when applied as seed treatment at the rate of 0.75 g a.i. kg^{-1} seed was most effective against the sucking pests (*Bemisia tabaci* and *Empoasca kerri*) upto four weeks of seed germination with least 6.71 insects/plant in soybean (Netam *et al.*, 2013). Seed treatment with Gaucho 600 FS at 3 g/kg seed could effectively control aphids (*Aphis craccivora*) in faba bean (Ahmed *et al.*, 2013).

2.2.1.2. Bioefficacy of imidacloprid as foliar treatment against insect pests

2.2.1.2. a. Bioefficacy of imidacloprid as foliar treatment in okra and cotton

Imidacloprid (Admire) has been reported to be extremely effective for control of *B. tabaci* in vegetable production (Elbert *et al.,* 1990; Mullins, 1993; Palumbo *et al.*, 2001).

Imidacloprid one per cent kept the leaf hopper population under check even up to 60 days after germination in okra (Mote *et al.*, 1995).

Attique and Ghaffar (1996) carried out a field trial with a treatment of confidor (imidacloprid) and promet (furathiocarb) and found that attack of *Amrasca devastans* was reduced up to 4 weeks.

Horowitz *et al.* (1998) reported that imidacloprid at 25 g a.i. ha^{-1} effectively controlled the whitefly, *B. tabaci* in cotton and adult mortality recorded at 2, 7 and 14 days after application were 90, 93, and 96 per cent respectively. It was observed that imidacloprid 200 SL was effective in controlling *A. biguttula biguttula* over a long period of time than other insecticides in okra (Faqir and Gul, 1998). Imidacloprid applied as foliar application (0.005 and 0.02 %) was proved to be very effective against leaf hoppers and protected the cotton crop till the initiation of spraying against bollworms up to 40 days after sowing (Gupta *et al.*, 1998).

Foliar spray of imidacloprid (100 mL ha^{-1}) resulted in 100 per cent mortality of *Amrasca devastans* for 10 days (Kumar and Santharam, 1999). Imidacloprid provided the best control of *A. gossypii* at 3 days after application in cotton with at least 96 per cent control (Albuquerque *et al.*, 1999).

Imidacloprid (25 g a.i. ha^{-1}) was observed to be effective in controlling okra jassids by recording 77.2-86.0 per cent reduction of jassid population even after 21 days after application when compared to control (Acharya *et al.*, 2002). But imidacloprid 20 g a.i. ha^{-1} also provided greatest control of jassids (Singh *et al.*, 2002). Imidacloprid at 25 g a.i. per ha proved significantly superior in controlling jassids in okra followed by dimethoate at 300 g a.i. per ha and cypermethrin at 100 g a.i. per ha (Misra, 2002). Spraying of okra with imidacloprid at 25 g a.i. ha^{-1} proved effective against okra leafhoppers upto three weeks after spray (Subhadhra Acharya *et al.*, 2002).

Razaq *et al.* (2003) illustrated that imidacloprid was effective against jassids (*Amrasca biguttula*) at 72, 168, and 240 h after spraying in cotton. Sharaf *et al.* (2003) observed that Confidor and Best also induced the highest initial activity on immature stages of whitefly in cotton.

Aslam *et al.* (2004) reported that imidacloprid (Confidor 200SL) at 80-250 ml/acre was the most effective up to seven days after treatment against cotton jassid (*Amrasca devastans*) and thrips (*Thrips tabaci*) in cotton. The efficacy of imidaclprid foliar spraying against *Helicoverpa armigera* has been reported (Ulaganathan and Gupta, 2004; Lavekar *et al.*, 2004 and Hussain and Bilal, 2007).

Two foliar sprays of imidacloprid 200 SL *viz.,* 100 and 125 mL ha^{-1} provided excellent control of leafhoppers and aphids up to 15 days after spraying in okra (Dey *et al.*, 2005). Imidacloprid proved to be the most effective against aphids causing a 98.17 per cent reduction as the general mean of the effect (El-Zahi, 2005). Imidacloprid (Confidor 200 SL at 500 ml/ha) gave statistically higher mortality of *A.biguttula biguttula* in cotton after 24 hours of insecticide application (Razaq *et al.* 2005).

Gosalwad *et al.* (2008) revealed that the neonicotinoids *viz.,* imidacloprid/ thiamethoxam at 20 g a.i. ha^{-1} effectively reduced the okra leafhopper population. Dhanalakshmi and Mallapur (2008) observed that imidacloprid and acetamiprid were most effective against aphids infesting okra. According to Sinha and Sharma (2008), a treatment schedule with three foliar sprays *viz*, imidacloprid-bifenthrin-endosulfan was most effective as it gave 9.30 per cent damage and that treatment was followed by imidacloprid seed treatment- endosulfan-endosulfan which gave 9.99 per cent and thiamethoxam- indoxacarb-indoxacarb which gave 10.30 per cent damage in terms of number of fruits.

With a higher dose of imidacloprid at 50 g a.i. ha^{-1} was applied, 100 per cent mortality of leafhoppers and aphids was observed up to 9 DAT (Preetha *et al.*, 2009). Imidacloprid (0.004 to 0.01 %) and thiamethoxam (0.005 % and 0.01 %) recorded equal efficacy against jassids (Kohle *et al.*, 2009). Foliar treatment with imidacloprid (Confidor 200SL) 250 mL acre^{-1} was effective against cotton whitefly *Bemisia tabaci* up to seven days after spraying in cotton (Amjad *et al.* (2009)).

Raghuraman and Birah (2011) reported that efficacy of imidacloprid 17.8 % SL at 80 g a.i. ha^{-1} significantly suppressed whitefly and leafhopper populations in cotton. El-Zahi and Aref (2011) observed that imidacloprid was the most effective against cotton aphids under field conditions. Imidacloprid 17.8 SL was most effective against aphids in transgenic cotton (Shivanna *et al.*, 2011).

Birah *et al.* (2012) evaluated an integrated module including seed treatment with imidacloprid at 5 g/kg seed a day before sowing +sowing of maize at the borders as barrier crop +weekly clipping of infested shoots and fruits +erection of pheromone trap at 100 traps ha^{-1} for mass trapping +foliar spray of neem seed kernel extract @ 30 mLL^{-1}, spinosad 45 SC @ 0.5 $mLL^{-1}$and karanj oil at 30 mL L^{-1} at 45, 60 and 75 days after sowing, respectively. The pooled results revealed that integrated module and bio-intensive module recorded significantly lower incidence of shoot borer (4.23 %) and fruit borer (5.64 %) and more fruit yield (8.66 t ha^{-1}) was recorded in integrated module as compared to untreated control, 13.42 per cent, 16.85 per cent and fruit yield of 5.25 t ha^{-1} respectively.

According to El- Naggar *et al.* (2013) treatments with imidacloprid as foliar applications were highly effective against hoppers and aphids up to 14 days, while the effect was moderate on the whitefly population (mature and immature stages) in cotton. Foliar application with imidacloprid 0.0089 per cent caused higher mortality of aphids, jassid, thrips and whitefly on Bt cotton (Ghelani, 2014).

2.2.1.2. b. Bioefficacy of imidacloprid as foliar treatment against insect pests of other crops

Sun-Jian-Zhong *et al.* (1996) reported that foliar application of 10 per cent imidacloprid WP at 15 or 30 g a.i. ha^{-1} against *Nilaparvatha lugens* (Stal.) in rice resulted in high effective population suppression (more than 90% control) for over 40 days after treatment.

Imidacloprid with low mammalian toxicity and longer persistence on the treated surface can safely be used for controlling the fruit borer *Helicoverpa armigera* infesting tomato (Mishra 1986, Singh and Singh, 1990, Bhatt and Patel 2002).

Seed treatment with imidacloprid 600FS at 0.16 mg (a.i./kg seed) was effective in reducing populations and exhibited systemic insecticidal activity against chinch bugs, flea beetle, wireworm, white grub, and southern corn leaf beetle in corn (Wilde *et al.*, 2004) Imidacloprid (Confidor) reduced the mean per cent population of whiteflies even 240 h after spraying in mung bean (Khattak *et al.*, 2004). Foliar spraying with imidacloprid (Confidor

18.3% w/w 200SC) at 2.5 mL L^{-1} was effective against controlling hispid beetle *Brontispa longissima* in various palms (He *et al.*, 2005).

Joshi and Sharma (2009) reported that Confidor 200 SL at 400 mL ha^{-1} treatment was the most effective against aphids *Rhopalosiphum maidis* (titch) in wheat. The insecticides Provado 1.6F (imidacloprid) at 222.39 ml ha^{-1} significantly suppressed the *Myzus persicae* population by 74.92 per cent in potato (Khan *et al.*, 2011).

Rouhani (2013) observed that imidacloprid 1 µl mL^{-1}, produced the highest mortality to *Aphis punicae* in pomegranate under laboratory conditions. According to Ghoshal *et al.*(2013) imidacloprid 17.8 SL @ 50 g a.i. ha^{-1}, was found superior against whiteflies, which received lowest number of whitefly population (1.55/plant) and offered maximum reduction of whiteflies (83.15%) as well as highest marketable fruit yield (146.50 q ha^{-1}) in brinjal. Further they reported that the efficacy of imidacloprid lasted for 25 days after application when compared with methyl demeton which persisted only for 10 days.

According to Das (2013) imidacloprid (Rally 20 SL) at 3 mL L^{-1}gave excellent result (96 per cent population reduction) against chilli aphid *Myzus persicae* (Hemiptera: Aphididae) at three days after spraying in chilly. Further he observed that imidacloprid action significantly persisted at least up to day 10 after the insecticide was sprayed in the field. Pachundkar *et al.* (2013) reported that imidacloprid 70 WG (0.015%) was effective against jassids (*Empoasca kerri*) in cluster bean (*Cyamopsis tetragonoloba*).

2.2.2 Imidacloprid against natural enemies

It was reported that imidacloprid 70 WS offered protection against *A. gossypii* upto 40 days in cotton when the seeds were treated at 5.0 g kg^{-1} and it was least toxic to predatory arthropods (Nauen and Elbert, 1994).

Imidacloprid showed little impact on beneficial insects when used as foliar spray on cotton (Mizell and Sconyer, 1992). But Smith and Krischik (1999) indicated that imidacloprid might not be compatible with the coccinellid predator *Coliomegilla maculata* because there was a significant decrease in the general mobility of the predator in imidacloprid treated plants. It was observed that the contact action of imidacloprid caused toxic effect against coccinellid up to 20 days (Viggiani *et al.*, 1999).

Katole and Patil (2000) studied the activities of natural enemies in seed treatment and foliar sprays with imidacloprid in cotton. Though non-significant difference in occurrence of natural enemies (coccinellids and chrysoperla) was noticed, the plots with seed treatments recorded relatively higher population of natural enemies as compared to foliar spays. Patil *et al.* (1995) reported from a laboratory study that imidacloprid at 0.07 per cent was persistent up to 15 days and caused 24.7 per cent mortality of *Coccinella sexmaculata* adults.

Imidacloprid 200 SL (0.004%) and acephate 75 SP (0.11%) were safe to predators like coccinellids, spiders and chrysopids as evidenced by the highest survival rate after the use of these insecticides under field condition (Chandrasekharan, 2001). Ruiz and Medina (2001) observed that the green lacewing *C. carnea* and imidacloprid were compatible and moderate plant viral infection in tomato by controlling the whitefly *B. tabaci.*

Seed treatment with imidacloprid under higher doses was observed to be attractive to the coccinellid predators in cotton (Satpute *et al.*, 2002). Imidacloprid was much less toxic to natural enemies than carbamate, organophosphorus, pyrethroid, etofenprox and acetamiprid (James and Coyle, 2001; Youn *et al.*, 2003). It was reported that imidacloprid at 0.025 per cent and acetamiprid at 0.002 per cent were safer to the aphid predators like *Menochilus sexmaculata* and *Coccinella transversalis* than organophosphate insecticides like chlorpyrifos (0.05%), profenofos (0.05%) and triazophos (0.05%) on cowpea (Varghese, 2003).

Kannan *et al.* (2004) observed that seed treatment of transgenic cotton with imidacloprid 5 g kg^{-1} seed was not only safe but also attracted predators, *viz.* coccinellid beetles, *Coccinella septumpunctata* (Linnaeus) and *Cheilomenes sexmaculata* (Fabricius); green lace wing, *Chrysoperla carnea* (Stephens) and Lynx spider, *Oxyopes javanus* (Thorell); orb spider, *Argiope minuta* (Karsh); wolf spider, *Lycosa pseudoannulata* (Boesenberg and Strand); long jawed spider, *Tetragnatha javana* (Thorell); *Neoscona theisi* (Walcknear) and *Peucetia viridana* (Stoliczka) in transgenic cotton. Seed treatment with imidacloprid 600FS at 10g kg^{-1} seed did not disturb the natural enemy population in okra (Tamilvel, 2004). In a study on the toxicity of imidacloprid to *C.carnea* in relation to organophosphates, Varghese and Beevi (2004) found that imidacloprid was the safest with LC_{50} value of 0.0997. Foliar application of imidacloprid 0.02 per cent was proved to be less toxic to coccinellid and spider population in okra (Tamilvel, 2004).

Dey *et al.* (2005) evaluated the influence of imidacloprid 70 WS as seed treatment chemical at the time of sowing and imidacloprid 200 SL as foliar spray at 20 and 40 days after sowing, on the natural enemies in cotton. Significantly higher number of predatory coccinellid grubs was recorded in imidacloprid treated plots, irrespective of formulation and dosages. Number of predatory coccinellid grubs or percentage of aphids parasitization did not differ significantly among the different formulations or dosages of imidacloprid in okra.

Ahmed *et al.* (2014) reported that imidacloprid (Confidor 200 SL) at 100 ml acre^{-1} was safe to natural enemies and toxic for the sucking pests as compared to conventional insecticides. The population observed were green lacewings (42.5-87.5 and 37.5-57.5), lady bird beetle (50.0-60.0 and 26.6-46.6) and pirate bug (28.0-60.0 and 24.0-57.0) in neonicotinoids and conventional insecticide treated plots, respectively.

Khani *et al.* (2012) revealed that the toxicity of imidacloprid (technical grade with 95% purity) was approximately 3 times higher than that of abamectin for citrus mealybug predator *C. montrouzieri* reared on *Planococcus citri* infested squash and potato. The estimated values of LC_{50} for female and male *C. montrouzieri* were 23.91and 17.25 µg a.i./mL (nanogram of active ingredient per insect) for imidacloprid and 66.73 and 67.21 µg a.i./mL (ng a.i insect^{-1}) for abamectin, respectively.

2.2.3 Effect of imidacloprid on plant growth parameters

Mote (1993) observed an increase of plant height and leaves with imidacloprid (1 to 5 per cent a.i. w/w) seed treatment of sorghum. The plant height, number of fruits per plant and yield were found to be superior in imidacloprid seed treated plants in okra (Mote *et al.*, 1994).

In cotton also, imidacloprid (Gaucho) seed treatments showed increased plant height over control (Graham *et al.*, 1995). Mote *et al.* (1995) reported that among various doses of imidacloprid 70 WS, 10g kg^{-1} cotton seed could check aphid and jassid population effectively upto 45 days besides phytotonic effect. According to Sreelatha and Divakar (1997) seed treatment with imidacloprid at 7.5 g per kg okra seed effectively controlled the aphids and jassids up to 35 days after germination and also increased the yield of okra.

Cotton yield was found to be increased with imidacloprid 70 WS at 7 g kg^{-1} seed (Kumar, 1998). It was observed that imidacloprid 200 SL has resulted in higher fruit yield (10.3 t ha^{-1}) which was not significantly different from monocrotophos + alpha-cypermethrin (11.85 t ha^{-1}) in okra (Faqir and Gul, 1998).

Seed treatment with imidacloprid 70 WS at 10 g kg^{-1} of bhindi seeds protected the crop and resulted in higher fruit yield (Sivaveerapandian, 2000). Imidacloprid 600 FS at 9 ml per kg seed and 70 WS at 10 g kg^{-1} seed were found to be promising against jassids and resulted in higher yields. Further, reported that plant height, greenness of leaves, leaf area, number of fruits per plant and yield were superior in plots treated with imidacloprid 600 FS and 70 WS than the untreated check in okra (Bhargava and Bhatnagar, 2001).

According to Dey *et al.* (2005), imidacloprid 70 WS at 5-10 g kg^{-1} seed did not show any adverse effect on plant growth of okra. Treatment of okra seeds with imidacloprid (Gaucho 600 FS -12 mL kg^{-1} seed) recorded significantly higher plant height, at 45, 55, 65 and 75 days after sowing (DAS) (38.47, 44.72, 53.22 and 62.22 cm, respectively, less number of days to flower initiation (38.1 days) over control (42.30 days), higher number of fruits (6.66) per plant and more fruit length (14.85 cm). Further reported that foliar treatment with imidaclorid recorded significantly higher number of leaves (16.47, 19.71 and 22.91) and is on par with foliar spray with imidacloprid at 55, 65 and 75 DAS (Praveen, 2005).

Verma and Kanwar (2009) observed that the plant height (141.63 cm) and average number of fruits (10.93/plant) in okra were on par with imidacloprid. Manjunath *et al.* (2009) reported a significantly higher fruit length (10.96 cm) in chilli with ZnSO4 + Captan +Imidacloprid.

Imidacloprid 17.8 SL at 50 g a.i. ha^{-1} was observed to be the best treatment which recorded highest incremental fruit yield in brinjal (70.01 q/ha) over the untreated check (Ghosal and Chatterjee, 2013).

2.2.4 Terminal residues of imidacloprid in fruits

Santharam *et al.* (2003) determined the residues of imidacloprid in chilli fruits when applied at 250, 375 and 500 mL ha^{-1} and reported that the residue was below detectable limit and below the codex EU MRLs, *i.e.*, 0.5 mg kg^{-1}.

Hassan *et al.* (2005) applied imidacloprid @ 345 g a.i. ha^{-1} and found its residues as 0.038, 0.020 and 0.015 ppm after 3 hours, 3 days and 7 days respectively, in the brinjal fruit by considering the MRLs for eggplant fruit 0.2 to 1 ppm.

Arora (2008) reported 4.8 and 6.1 µg kg^{-1} residues of imidacloprid in okra and brinjal fruits, from the IPM fields when applied at 0.01 per cent after 1 day while from Non IPM fields it was 8.5 µg kg^{-1}.

Akbar *et al.* (2010) conducted a study to find out the degradation of three conventional insecticides (imidacloprid, endosulfan and profenofos and two bioinsecticides (biosal and spinosad) sprayed on okra crop. The insecticides were sprayed at the rates of 49.4, 642.2, 988, 35.5 and 1.58 g. a. i. ha^{-1} respectively. The insecticide residues were analyzed in the leaf and cabbage heads after 0, 1, 3 and 7 days using high performance liquid chromatography. Conventional insecticides were found to be more persistent in the crop (average half life: 1.95, 2.42 and 1.57 days for imidacloprid, endosulfan and profenofos respectively) than bioinsecticides (average half life 1.25 and 0.27 days for spinosad and biosal). Residues of all tested insecticides were compared with codex and EU MRLs (MRL 0.5 mg kg^{-1}) and found that imidacloprid being biorational (low risk) was safe for consumption on the next day of application.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation entitled "Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) Moench)" was undertaken in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara, Kerala Agricultural University during 2013- 2014. The study was carried out by conducting two field experiments at the Instructional Farm, College of Horticulture in two seasons *viz.,* April 2013 to July 2013 and October 2013 to January 2014 under the prevailed weather conditions (Appendix I).

The materials used and the methodology adopted to achieve the objectives of the present investigation are presented in this chapter.

3.1 Conduct of field experiment

The biological efficiency of two neonicotinoid insecticides *viz.,* thiamethoxam and imidacloprid on insect pests of okra in field was evaluated by applying thiamethoxam and imidacloprid in three methods *viz.,* seed treatment, foliar spraying and a combination of seed treatment followed by foliar application on okra. Two field trials in two seasons from April to July 2013 (summer) and October to January 2014 (rainy) were carried out (Plate 1). The field experiments were laid out in Randomized Block Design with eight treatments replicated thrice in plots of size 2x2 m^2 with the variety, Arka Anamika, raised at 60 x 45 cm spacing by following all the recommended agronomic practices. Treatments of the experiment consisted of thiamethoxam and imidacloprid along with quinalphos as a standard recommended check insecticide for comparison and an untreated check. The treatments were thiamethoxam 30FS (Cruiser® 350 FS) @ 3 g a.i. kg^{-1} and imidacloprid 48 FS (Gaucho® 600 FS) @ 6 g a.i. kg^{-1} as seed treatments (ST) at sowing time, two foliar sprayings (2FT) with thiamethoxam 25 WG @ 25g a.i. ha^{-1} and imidacloprid 70 WG @ 25 g a.i. ha^{-1} at 15 and 30 days after sowing (DAS) and a combination of seed treatment followed by a foliar spraying (ST+FT) at 30 DAS. The standard check insecticide quinalphos 25 EC @ 250 g a.i. ha^{-1} was applied as two foliar sprayings (2FT) at 15 and 30 DAS. Details of treatments applied in field experiments are given in Table 1.

Table 1. Treatment details of field experiment on “Bioefficacy of neonicotinoid insecticides again insect pests of okra”

Treatments	Commercial Formulation	Dosage of insecticide	Method and time of application	Source of insecticide
T1- ST: Thiamethoxam (a.i. 30% w/w)	Cruiser 350FS	3 g a.i. kg $^{-1}$	Seed treatment Sowing time	Syngenta India Limited, Mumbai
T2- ST: Imidacloprid (a.i. 48 % w/w)	Gaucho 600FS	6 g a.i. kg $^{-1}$	Seed treatment Sowing time	Bayer Crop Science Limited, Mumbai
T3- FT: Thiamethoxam	Actara 25WDG	25g a.i. ha $^{-1}$	Foliar spraying 15 and 30DAS	Syngenta India Limited, Mumbai
T4- FT: Imidacloprid	Admire 70WDG	25g a.i. ha $^{-1}$	Foliar spraying 15 and 30DAS	Bayer Crop Science Limited, Mumbai
T5- ST+ FT : Thiamethoxam	Cruiser 350FS + Actara 25WDG	3 g a.i. kg $^{-1}$ + 25g a.i. ha $^{-1}$	Seed treatment + Foliar spraying	Syngenta India Limited, Mumbai
T6- ST+ FT : Imidacloprid	Gaucho 600FS + Admire 70WDG	6 g a.i. kg $^{-1}$ + 25g a.i. ha $^{-1}$	Seed treatment + Foliar praying at 30DAS	Bayer Crop Science Limited, Mumbai
T7- FT: Quinalphos (Standard Check)	Ekalux 25EC	250g a.i. ha $^{-1}$	Foliar spraying 15 and 30DAS	Syngenta India Limited, Mumbai
T8- UC: Untreated Control	-	-	-	-

ST - Seed Treatment FT - Foliar Treatment DAS - Days After Sowing UC - Untreated control

3.1.1. Methods of insecticide treatment applications

Thiamethoxam and imidacloprid along with the standard recommended check quinalphos were applied by three methods in the field trials.

3.1.1.a. Seed treatment before sowing

Healthy okra seeds, at the recommended seed rate, were soaked in water kept in two separate beakers for overnight. After draining out the water, seed dressing formulations of thiamethoxam 30 FS @ 3g a.i. kg^{-1} (10 mL kg^{-1} seed) and imidacloprid 48 FS @ 6g a.i. kg^{-1} (12.5 mL kg $^{-1}$ seed) were added to beakers containing the seeds and stirred well ensuring that all seeds were uniformly coated with the formulations (Plate 2). The seeds thus treated were then allowed to dry in the shade for three hours and sown immediately in respective plots in the field.

3.1.1. b. Foliar application of insecticides at 15 and 30 DAS

Thiamethoxam 25 WDG @ 25 g a.i. ha^{-1}, imidacloprid 70 WDG @ 25 g a.i. ha^{-1} and quinalphos 25 EC @ 250 g a.i. ha^{-1} were applied as foliar spraying. Spray solutions at the correct concentrations were prepared in water and sprayed at the rate of 500 L ha^{-1} by using a high volume knapsack sprayer on okra plants in the respective plots of field at 15 and 30 DAS.

3.1.1. c. Combination of seed treatment followed by a single foliar application at 30 DAS

Seeds were sown after seed treatment with thiamethoxam 30 FS and imidacloprid 48 FS. Thirty days after sowing, a single foliar spraying with thiamethoxam 25 WDG @ 25 g a.i. ha^{-1} and imidacloprid 70 WDG @ 25 g a.i. ha^{-1} was given by using a high volume knapsack sprayer at the rate of 500 L ha^{-1} on okra plants in the respective plots of the field.

3.2. Studies from field experiment

The following studies were made from okra field experiments conducted in two seasons.

3.2.1. Bioefficacy of thiamethoxam and imidacloprid on sucking and chewing pests

3.2. 2. Safety of of thiamethoxam and imidacloprid to natural enemies in the field

Plate 1. Experimental field

3.2.3. Effect of thiamethoxam and imidacloprid on plant growth parameters of okra

3.2.4. Persistence of thiamethoxam and imidacloprid residues in okra fruits

3.2.1. BIOEFFICACY OF THIAMETHIOXAM AND IMIDACLOPRID ON MAJOR INSECT PESTS OF OKRA

3.2.1.1 Bioefficacy of thiamethoxam and imidacloprid on major sucking pests of okra

The bioefficacy of thiamethoxam and imidacloprid against the leafhopper *Amrasca biguttula biguttula* Ishida, aphid *Aphis gossypii* Glover and white fly *Bemisia tabaci* Gennadius was assessed from their population density in field experiments conducted during two seasons (Plate 3).

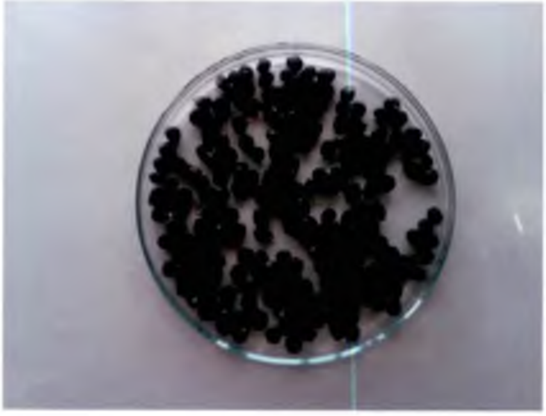
3.2.1.1.1 Effect of thiamethoxam and imidacloprid on *Amrasca biguttula biguttula* Ishida

The biological efficacy of thiamethoxam and imidacloprid on *A.biguttula biguttula* in field was studied in two seasons by monitoring its population incidence in all treatment plots of the field experiment at different days after treatment application. The population of nymphs of *A.biguttula biguttula* (Plate 3a) was observed and recorded from randomly selected three plants per plot. From each plant, three leaves - one each from top, middle and bottom canopy- were observed and counted the number of nymphs present on them. The observations on population counts were recorded at five days interval from 15 days after sowing (DAS) till 50 DAS. In the treatment plots with two foliar sprayings, given at 15 and 30 DAS, population counts were taken at 15 DAS (just before spraying), 16 DAS (one day after spraying), 20 DAS (5 days after spraying), 25 DAS (10 days after spraying), 30 DAS (15 days after spraying), 31 DAS (1 day after second spray), 35 DAS (5 days after second spray), 40 DAS (10 days after second spray), 45 DAS (15 days after second spray) and 50 DAS (20 days after second spray). Mean values of leafhopper population per three leaves per plant were worked out from the recorded observations.

3.2.1.1.2. Influence of thiamethoxam and imidacloprid on *Aphis gossypii* Glover

The influence of thiamethoxam and imidacloprid on the population density of *A. gossypii* was studied by recording the population density from randomly selected three plants per treatment plot. Three leaves- one leaf each from top, middle and bottom- on each of the selected plant were observed for aphid incidence and counted the population (Plate 3c). Aphid counts were taken by placing a card board sheet, having a window size 1 cm^2, on the

Plate 2. Seed treatment with thiamethoxam 350FS and imidacloprid 600FS



2a. Untreated okra seed

2b. Treatment with thiamethoxam 30 FS

2c. Treatment with imidacloprid 48 FS

ventral surface of the leaf. Aphids in the window region were counted with the help of a hand lens. The observations were recorded at five days interval from 15 DAS to 50 DAS as described in 3.2.1.1.1. Mean values of aphid population per three leaves per plant were worked out from the recorded observations.

3.2.1.1.3. Toxicity of thiamethoxam and imidacloprid to whitefly *Bemisia tabaci* Gennadius

Toxicity of thiamethoxam and imidacloprid to whitefly in okra was studied by recording the counts of both nymphs and adults present on three leaves (Plate 3e) from randomly selected three plants per plot in the morning before 9 AM. The observations were recorded at five days interval from 15 DAS to 50 DAS. Mean values of whitefly population per plant were worked out from the recorded observations.

3.2.1.2. Bioefficacy of thiamethoxam and imidacloprid on major chewing pests in okra

Field efficacy of thiamethoxam and imidacloprid on leaf roller *Sylepta derogata* Fabricius and shoot and fruit borer *Earias vitella* Fabricius was studied by assessing their damage in the field experiments conducted in two seasons (Plate 4).

3.2.1.2.1 Assessment of damage by leaf roller, *Sylepta derogata* Fabricius

Thiamethoxam and imidacloprid were evaluated for their bioefficacy against leaf roller by observing and recording its damage symptom (Plate 4e) in the field trials during the two seasons. Five plants were selected randomly in each plot and observed for the damage at 5 days interval starting from 30 days after sowing following the appearance of first incidence. The damage was assessed by counting the damaged leaves and total leaves in the selected plant and worked out the mean per cent leaf damage.

$$\text{Leaf damage (per cent)} = \frac{\text{No. of infested leaves per plant}}{\text{Total no. of leaves per plant}} \times 100$$

3.2.1.2.2 Effect of thiamethoxam and imidacloprid on shoot borer *Earias vitella* Fabricius

The incidence of shoot borer as influenced by the application of thaimethoxam and imidacloprid was studied in the field experiments during two seasons. The shoot damage was observed and recorded from five randomly selected plants in each plot at 10 days interval

Plate 3. Major sucking pests of okra with damage symptoms

3a. ***Amrasca biguttula biguttula***

3b. Hopper burn symptom

3c. ***Aphis gossypii***

3d. Stunting of okra plant

3e. ***Bemisia tabaci***

3f.Yellow vein mosaic symptom

starting from the occurrence of the shoot damage symptom by counting the withered shoots and total shoots in the selected plants. The per cent shoot damage per plant was worked out.

$$\text{Shoot damage per plant (per cent)} = \frac{\text{No. of infested shoots per plant}}{\text{Total no.of shoots per plant}} \times 100$$

3.2.1.2.3. Potency of thiamethoxam and imidacloprid against fruit borer *E. vitella*

Fruit borer damage in terms of number and weight was assessed by observing the damage symptom on fruits (Plate 4d) at the time of harvesting. Five plants were randomly tagged in each treatment at the time of harvest for recording the damage. Fruits were harvested at two days interval and observations were taken on the number and weight of total fruits and those of infested fruits at each harvest. The mean per cent fruit damage per plant was worked out after completing all harvests.

$$\text{Per cent fruit damage (number)} = \frac{\text{No.of damaged fruits per plant}}{\text{Total number of fruits per plant}} \times 100$$

$$\text{Per cent fruit damage (weight)} = \frac{\text{Weight of damaged fruits per plant}}{\text{Total weight of fruits per plant}} \times 100$$

3.2.2 IMPACT OF THIAMETHOXAM AND IMIDACLOPRID ON NATURAL ENEMIES IN OKRA ECOSYSTEM

The population of predators *viz.* coccinellids, spiders and other natural enemies observed in all treatment plots of okra was observed and recorded.

3.2.2.1. Coccinellids

Counts of both adults (Plate 5) and grubs of coccinellids present on five randomly selected plants in each treatment plot were recorded. The observations were taken at ten days interval starting from 20 days after sowing to 50 days after sowing and the mean values were worked out.

Plate 4. Major chewing pests of okra with damage symptom

4a. ***Earias vitella*** **larva**

4b. ***Earias vitella*** **adult**

4c.Withering of shoot

4d. Fruit damage

4d. ***Sylepta derogata*** **damage**

4e. ***Sylepta derogata*** **adult**

3.2.2.2. Spiders

Population of spiders (Plate 6) in different treatments was recorded from randomly selected five plants in each treatment plot at twenty days interval from 20 days after sowing to 60 days after sowing. Mean values were worked out.

3.2.2.4. Other natural enemies

The incidence of other predators (Plate 7) such as syrphid, lacewing and rove beetle present in the field were observed. Counts were recorded from five randomly selected plants in each plot at twenty days interval from 20 days after sowing. Means were calculated on per plant basis.

3.2.3. Influence of thiamethoxam and imidacloprid on plant growth parameters of okra

Vegetative and reproductive growth parameters of okra as influenced by thiamethoxam and imidacloprid were studied in the field experiments. Five plants in each plot were tagged randomly to study the effect of thiamethoxam and imidacloprid on different plant growth parameters namely height of the plant, number of leaves , days for flower initiation, number of flowers , number of fruits , fruit weight and fruit length.

3.2.3.1. Height of the plant

From the tagged plants as described in 3.2.3, height of the okra plant was measured from ground level to the tip of the main stem using a meter scale, at 60 days after sowing. The mean value of five plants was worked out.

3.2.3.2. Leaves per plant

Total number of leaves- both matured and tender leaves- present in each of the five selected plants was counted at 60 days after sowing and worked out the mean leaves per plant.

3.2.3.3. Days for flower initiation

Number of days taken to initiate flowering in the selected plants in different treatment plots was observed and recorded the days. The mean number of days for flower initiation was worked out.

Plate 5. Natural enemies – Coccinellids

5a. *Coccinella transversalis* Fabricius

5b. *Cheilomenes sexmaculata* (Fabricius)

5c. *Pseudaspidimerus* sp.

5d. *Micraspis discolor* (Fabricius)

3.2.3.4. Flowers per plant

Five plants were selected at random from each treatment plot and tagged at the onset of reproductive stage of the plant for taking observations on flower production. From the selected plants, observation on the number of flowers produced in each plant were taken at five days interval from each plant till 65 DAS. Mean number of flowers produced per plant was worked out.

3.2.3.5. Fruits per plant

From each of the five tagged plants, fruits were separately harvested at 2 days interval starting from 45 DAS. A total of 12 harvests were taken. Total no.of fruits harvested from each plant was recorded and worked out mean values.

3.2.3.6. Fruit length

From each harvest of fruits, three fruits were randomly selected from each plant and measured the length by using a scale. The mean values were worked out.

3.2.3.7. Fruit weight per plant

After recording the length of fruits as described in 3.2.3.6, the fruit weight was also taken by using a balance and worked out the mean fruit weight per plant.

3.2.4. Persistence of thiamethoxam and imidacloprid residues in okra fruits

From all the treatments at 45 DAS (15 days after second spraying) fruits were harvested and analysed for insecticide residue in the laboratory of AINP on Pesticide Residue, College of Agriculture, Vellayani, Kerala Agricultural University. Residues of thiamethoxam and imidacloprid were analysed using Liquid chromatography – Mass Spectrometry (LC - MS) and quinalphos residues were analysed using Gas chromatography-Mass Spectrometry (GC - MS). Weighed 25 g of fruit sample and blended with 50ml of acetonitrile (CH_3CN) and homogenized at 14000 rpm. The homogenized sample was taken in a sample tube and added 10g sodium chloride (NaCl), shaken and centrifuged at 2000 to 2500 rpm for 4 minutes. From this, 16ml of supernatant was collected and added 6g sodium sulphate (Na_2SO_4) and mixed well. From the supernatant, 12 ml was then transferred to 15 ml tube containing 0.2 g PSA (Primary secondary amine) and magnesium sulphate ($MgSO_4$) and vortexed for 30 seconds. It was then allowed to centrifuge for 3 minutes at 2500 rpm. For

Plate 6. Natural enemies- spiders

6a. Unidentified species

6b. *Oxyopes javanus*

6c. Unidentified species

6d. Unidentified species

Plate 7. Other natural enemies

7a.Greenlacewing grub (*Chrysoperla* sp.)

7b. Rove beetle (*Paederus* sp.)

7c. Syrphid maggots (*Ischiodon* sp.)

LC, from the supernatant 5ml was taken and evaporated the acetonitrile in Turbo Vap at 45^0 C and reconstituted to 2ml using methanol. For GC, from the supernatant, 4ml was taken and evaporated the acetonitrile in Turbo Vap at 45^0 C and reconstituted to 1ml using n-Hexane. The reconstituted samples were poured into GC and LC tubes and labelled properly. The samples were then injected into GC and LC columns separately. For LC, the column used was Atlantis dc-18 and column temperature was 40^0 C and for GC the column used was DBI and the injection temperature was 275^0 C. The residues were calculated using the formula,

Residue = Area of sample in the graph x Conc. of Standard x Dilution Factor/ Area of Standard

(ppm)

Statistical analysis of the data

The data recorded from each season field experiment were analyzed separately by one-way analysis of variance and Duncan's multiple range test (Duncan, 1955) using MSTAT - C (1991). Pooled analysis of two seasons data was also conducted. The effect of treatments was also worked in terms of percent reduction over untreated control as per the equation given below.

$$\text{Per cent reduction over control} = \frac{\text{(No. of insects in the control} - \text{No. of insects in the treatment)}}{\text{No. of insects in the untreated control}} \times 100$$

RESULTS

4. RESULTS

Two neonicotinoid insecticides - thiamethoxam and imidacloprid - applied in three different methods, *viz.,* seed treatment at sowing (ST), two foliar sprayings (2 FT) at 15 and 30 days after sowing (DAS) and a combination of seed treatment followed by a single foliar spray (ST+FT) at 30 DAS, were evaluated for their biological efficiency on okra during two seasons in the field. Quinalphos 25EC, as foliar spraying at 15 DAS and 30 DAS, was also included as a standard check insecticide for comparison. Results of the studies conducted on the bioefficacy against insect pests, safety to natural enemies, influence on plant growth parameters and terminal insecticide residues in okra fruits are presented in this chapter.

4.1 bioefficacy of thiamethioxam and imidacloprid on major insect pests of okra

4.1.1. Seed treatment and foliar sprayings with thiamethoxam and imidacloprid against *Amrasca biguttula biguttula* Ishida

Season-1 (2013-14)

Results on the effect of thiamethoxam and imidacloprid on *A. biguttula biguttula* in the first season (2013-14) are presented in Table 2. Seed treatment (T1 - ST) with thiamethoxam @ 3g a.i. kg^{-1} and (T2 - ST) imidacloprid @ 6 g a.i. kg^{-1} recorded no incidence of *A. biguttula biguttula* till 16 days after sowing (DAS). Thereafter, the population density showed a gradual increase from 0.66 (20 DAS) to 29.00 leafhoppers per plant (50 DAS) in ST thiamethoxam and from 0.66 (20DAS) to 32.66 (50 DAS) in ST imidacloprid. The mean population density during the season in ST thiamethoxam was found to be 7.33 and 8.99 in ST imidacloprid indicating 76.92 and 71.69 per cent reduction of the population over untreated control. However, ST thiamethoxam and imidacloprid showed no significant difference in the leafhopper population between them at different DAS throughout the season.

The T3- Two foliar sprayings (2 FT) with thiamethoxam @ 25 g a.i. ha^{-1} at 15 and 30 DAS - recorded 0 at 1 day after treatment(1 DAT-1st spray) at16 DAS to 2.33 hoppers (15 DAT- 1st spray) at 30 DAS. After the 2nd spray, the population varied from 0.33 at 31 DAS (1 DAT- 2nd spray) to 22 hoppers at 50 DAS (20 DAT- 2nd spray) with a mean of 5.26 hoppers per plant during the season. The leafhopper population in imidacloprid 2FT (T4) also showed the same trend wherein the population varied from 3.66 at15 DAS before spraying to 26.66 after two

Table 2. Seed treatment and foliar sprayings of thiamethoxam and imidacloprid against *A. biguttula biguttula* on okra (Season 1)

Treatments	Mean number of leaf hopper per three leaves per plant										Mean population	% reduction over UC
	Days After Sowing (DAS)											
	15	†16	20	25	30	†31	35	40	45	50		
T$_1$. ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.00	0.00	0.66	1.00^{c} (1.22)	2.00^{d} (1.58)	2.66^{b} (1.76)	6.67^{b} (2.66)	12.33^{b} (3.57)	19.00^{d} (4.41)	29.00^{cd} (5.42)	7.33	76.92
T$_2$ - ST Imidacloprid 48 FS @ 6g a.i. kg $^{-1}$	0.00	0.00	0.66	1.00^{c} (1.22)	2.00^{d} (1.56)	2.67^{b} (1.77)	7.66^{b} (2.84)	13.00^{b} (3.66)	30.33^{b} (5.55)	32.66^{c} (5.75)	8.99	71.69
T$_3$ - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	3.66	0.00	0.00	1.33^{c} (1.34)	2.33^{cd} (1.67)	0.33^{c} (0.87)	3.00^{c} (1.85)	6.33^{d} (2.61)	13.67^{e} (3.75)	22.00^{e} (4.74)	5.26	83.43
T$_4$- 2 FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	3.66	0.00	0.00	1.33^{c} (1.34)	3.00^{cd} (1.85)	1.33^{b} (1.34)	4.00^{c} (2.11)	7.67^{cd} (2.84)	14.66^{e} (3.89)	26.66^{de} (5.21)	6.23	80.38
T$_5$ - ST+ FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25 g a.i. ha^{-1}	0.00	0.00	0.33	1.00^{c} (1.22)	2.33^{cd} (1.67)	0.33^{c} (0.87)	3.33^{c} (1.95)	7.33^{cd} (2.79)	16.66^{de} (4.13)	25.33^{de} (5.079)	5.36	83.12
T$_6$ - ST+ FT Imidacloprid 48 FS @ 6g a.i. kg $^{-1}$ + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.00	0.66	1.00^{c} (1.17)	4.00^{bc} (2.11)	1.66^{b} (1.46)	4.00^{c} (2.11)	9.66^{bcd} (3.18)	17.33^{de} (4.21)	30.00^{cd} (5.52)	6.83	78.49
T$_7$- 2 FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	4.00	0.00	1.66	3.00^{b} (1.85)	5.66^{b} (2.47)	2.33^{b} (1.67)	6.66^{b} (2.67)	11.00^{bc} (3.34)	23.66^{c} (4.91)	39.33^{b} (6.31)	9.73	69.26
T$_8$ - Untreated Control	4.00	4.66	6.33	9.00^{a} (3.08)	16.33^{a} (4.10)	19.33^{a} (4.45)	22.33^{a} (4.77)	35.00^{a} (5.95)	97.33^{a} (9.88)	103.33^{b} (10.18)	31.76	
CD Value (5%)				0.39	0.42	0.39	0.37	0.57	0.47	0.47		

ST - Seed Treatment, FT - Foliar Treatment, UC - Untreated control, † - One day after spraying

Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

sprayings at 50 DAS with a mean population of 6.23 hoppers per plant. Thiamethoxam 2FT indicated 83.43 percent reduction of population while imidacloprid showed 80.38 per cent population reduction as compared to untreated control. However, both of them were on par.

The T5- combination of seed treatment followed by foliar treatment at 30 DAS with thiamethoxam (ST +FT thiamethoxam) and imidacloprid (T6)- recorded no incidence upto 16 DAS. Thereafter, leafhopper population increased from 0.33 (20 DAS) to 2.33 (30 DAS). After the foliar spraying, the population varied from 0.33 to 25.33 (20 DAT) hoppers per plant at 50 DAS. The T4- Imidacloprid seed treatment followed by foliar treatment (ST +FT imidacloprid) showed 0 to 4.00 (30 DAS) and 1.66 (1 DAT) to 30.00 (20 DAT) hoppers at 50 DAS. Population mean of the season was 5.36 in thiamethoxam and 6.83 in imidacloprid resulting in 83.12 and 78.49 per cent reduction of population. However, both T5 and T6 showed no significant difference in the hopper population.

The standard check treatment (T7) with two foliar sprayings (FT) of quinalphos @ 250 g a.i. ha^{-1} recorded no incidence at 16 DAS (1 DAT- 1st spray) and then the population increased to 5.66 (15DAT- 1st spray)at 30 DAS. At 1 DAT- 2nd spray, again reduced to 2.33 (31 DAS) and thereafter increased to 39.33 (20 DAT- 2nd spray) at 50 DAS. Population mean in FT quinalphos during the season was found to be 9.73 hoppers per plant. Among all the treatments, quinalphos (T7) brought about the lowest reduction (69.26 per cent) of leafhopper population over untreated control with a mean of 31.76 hoppers per plant in the untreated control.

The data thus revealed that both thiamethoxam and imidacloprid were significantly superior to quinalphos in lowering the hopper population. All the three methods of application were effective against leafhoppers. ST with thiamethoxam and imidacloprid indicated 71.69 to 76.92 per cent reduction of population while 2FT brought about 80.38 to 83.43 per cent reductions. ST +FT combination resulted in 78.49 to 83.12 per cent reduction of the hopper population. Two foliar sprays of thiamethoxam (2FT) recorded the lowest mean population (5.26) bringing about the highest reduction (83.43 per cent) closely followed by ST+FT thiamethoxam (83.12%). Upto 30DAS, both thiamethoxam and imidacloprid by all the three methods of application of ST ,FT and ST+FT were significantly superior to quinalphos and the untreated control. At 35 DAS, ST was on par with quinalphos while 2FT and ST+FT were equally effective. From 40DAS, both FT and ST+FT showed no significant difference in the population. The standard recommended quinalphos (2 FT) showed the lowest (69.26%) reduction in hopper population as compared to thiamethoxam and imidacloprid.

Season 2 (2013-14)

In season 2 also, no incidence of leafhoppers (Table 3) was observed in ST thiamethoxam and ST imidacloprid upto 16 DAS. Thereafter, the population increased from 1.00 (20 DAS) to 132.33 (50 DAS) in ST thiamethoxam and from 1.33 (20 DAS) to 125.33 (50 DAS) in ST imidacloprid showing a mean population of 26 and 25.16 hoppers per plant.

Two FT (15 and 30 DAS) thiamethoxam @ 25 g a.i. ha^{-1} indicated 0 (1 DAT- 1st spray) to 3.00 hoppers (15 DAT- 1st spray) at 30 DAS and 0.66 (1 DAT- 2nd spray) to 57.66 hopper (20 DAT- 2nd spray) at 50 DAS. In the case of imidacloprid FT, the hopper population varied from 0 (1 DAT- 1st spray) to 3.00 (15 DAT- 1st spray) at 30 DAS and 1.33 (1 DAT- 2nd spray) to 120.33 (20 DAT- 2nd spray) at 50 DAS.

In ST +FT thiamethoxam, the population of hoppers varied from 0 (15 DAS) to 5.00 (30 DAS). When a foliar spray was given at 30 DAS, the population started declining and the population varied from 0.33 (1DAT) to 63.66 (20 DAT) at 50 DAS. In combination treatment with imidacloprid, the population was 0.00 at 16 DAS and the population started increasing to 4.33 at 30 DAS. With the foliar spray at 30 DAS, the population was observed to vary from 2.00 (1DAT) to 72.33 (20 DAT) at 50 DAS.

Two FT quinalphos at 250 g a.i. ha^{-1} indicated a population 0.00 (1 DAT) to 6.00 (15 DAT-1st spray) and 3.66 (1 DAT-2nd spray) to 123.33 (20 DAT-2nd spray) at 50 DAS with 30.84 per cent population. The untreated control plot showed a high population throughout the crop period ranging from 0.33 (15 DAS) to 154.00(50 DAS) hoppers per plant.

During the 2nd season also, FT thiamethoxam continued to record the lowest (8.49) mean hopper population showing the highest population reduction (72.6%) followed by ST+FT

Table 3. Seed treatment and foliar sprayings of thiamethoxam and imidacloprid against *A. biguttula biguttula* (Season 2)

Treatments	Mean number of leaf hopper per three leaves per plant										Mean population	% reduction over UC
	Days After Sowing (DAS)											
	15	†16	20	25	30	†31	35	40	45	50		
T_1 - ST Thiamethoxam 30 FS @ 3 g ai kg^{-1}	0.00	0.00	1.00	2.33^{a} (1.67)	4.00^{b} (2.12)	8.33^{b} (2.97)	10.33^{b} (3.29)	34.33^{b} (5.89)	36.66^{bc} (6.07)	132.33^{ab} (11.52)	22.93	26.00
T_2 - ST Imidacloprid 48 FS @ 6g ai kg^{-1}	0.00	0.00	1.33	2.00^{a} (1.56)	5.00^{b} (2.33)	8.33^{b} (2.96)	10.33^{b} (3.29)	29.00^{bc} (5.43)	50.67^{a} (7.13)	125.33^{b} (11.20)	23.19	25.16
T_3 - 2FT Thiamethoxam 25 WDG @ 25 g aikg^{-1}	0.00	0.00	0.00	1.33^{a} (1.34)	3.00^{b} (1.85)	0.66^{e} (0.99)	1.66^{c} (1.46)	6.66^{d} (2.67)	14.00^{d} (3.79)	57.66^{c} (7.61)	8.49	72.60
T_4 - 2FT Imidacloprid 70 WDG @ 25g ai ha^{-1}	0.00	0.00	0.00	1.66^{a} (1.46)	3.00^{b} (1.86)	1.33^{de} (1.34)	2.00^{c} (1.56)	7.00^{d} (2.73)	29.67^{c} (5.49)	120.33^{b} (10.99)	16.49	46.78
T_5 - ST+FT Thiamethoxam 30 FS @ 3g ai kg^{-1} + Thiamethoxam 25 WDG @ 25 g ai ha^{-1}	0.00	0.00	1.00	2.33^{a} (1.67)	5.00^{b} (2.33)	0.33^{e} (0.87)	1.66^{c} (1.46)	9.66^{d} (3.18)	18.33^{d} (4.33)	63.66^{c} (7.99)	10.19	67.12
T_6 - ST+FT Imidacloprid 48 FS @ 6g ai kg^{-1} + Imidacloprid 70 WDG @ 25g ai ha^{-1}	0.00	0.00	0.66	1.33^{a} (1.34)	4.33^{b} (2.19)	2.00^{cd} (1.56)	3.00^{c} (1.86)	8.66^{d} (3.03)	30.00^{c} (5.52)	72.33^{c} (8.48)	12.23	60.53
T_7 - 2FT Quinalphos 25 EC @ 250 g ai ha^{-1} (Standard check)	0.00	0.00	1.33	3.00^{a} (1.81)	6.00^{b} (2.53)	3.66^{c} (2.03)	8.33^{b} (2.96)	26.33^{c} (5.18)	42.33^{ab} (6.54)	123.33^{b} (11.12)	21.43	30.84
T_8- Untreated Control	0.33	1.00	1.66	4.66^{a} (2.25)	10.66^{a} (3.29)	17.00^{a} (4.17)	21.66^{b} (4.70)	46.66^{a} (6.84)	52.33^{a} (7.25)	154.00^{a} (12.41)	30.99	
CD Value (5%)				1.64	0.60	0.50	0.37	0.55	0.78	1.06		

ST - Seed Treatment, FT - Foliar Treatment, UC - Untreated control, † - One day after spraying

Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

thiamethoxam (67.12%) and ST+FT imidacloprid (60.53%). ST thiamethoxam and imidacloprid reduced 25.16 to 26 per cent population in the season and were on par. Two FT quinalphos was significantly less effective as it recorded lowest (30.84 %) reduction of the population.

Pooled analysis

Result of data of two seasons were pooled and statistically analyzed to understand the overall impact of thiamethoxam and imidacloprid on the population density of leaf hoppers. The results of the pooled analysis are given in Table 4.

The results revealed that in (T1) the seed treatment (ST) plot with thiamethoxam, the population varied from 1.66 at 25 DAS to 80.66 at 50 DAS with a mean of 21.49 hoppers per plant as against 43.54 hoppers in the untreated control. In seed treatment with imidacloprid the population varied from 1.50 (25 DAS) to 78.99(50 DAS) with a mean of 22.85 hoppers per plant. Population showed no significant difference between seed treatments of thiamethoxam and imidacloprid.

In the treatment (T3) with two foliar applications of thiamethoxam (2FT thiamethoxam) hopper population increased from 1.33 (10 DAT- 1st spray) at 25 DAS to 2.66 (15 DAT-1st spray) at 30 DAS. One day after the 2nd spray at 31 DAS (1 DAT) the population decreased to 0.50 and then increased to 39.83 (15 DAT) at 50 DAS. In foliar treatment (2 FT) with imidacloprid (T3) the population varied from 1.5 (10 DAT-1st spray) at 25 DAS to 2.66 (15DAT-1st spray) at 30 DAS and 1.33 (1 DAT-2nd spray) at 31 DAS to 73.49 (20 DAT-2nd spray) at 50 DAS.

The combination (T5) of seed treatment followed by foliar treatment with thiamethoxam (ST+ FT) recorded 1.66 at 25 DAS to 3.66 at 30 DAS and 0.33 (1DAT) to 44.50 hoppers per plant (20DAT) at 31 DAS and 50 DAS . ST+FT imidacloprid (T5) showed 1.17 to 4.16 hoppers (25 DAS to 30 DAS) and 1.83 to 51.16 from 1 DAT (31 DAS) to 20 DAT (50 DAS).

Two foliar sprayings (T7) with quinalphos @ 250 g a.i.ha^{-1} indicated a population of 3.00 (10 DAT) at 25 DAS to 5.83 (15 DAT) at 30 DAS and 3.00(1 DAT) at 31 DAS to 81.33 (20

Table 4. Seed treatment and foliar sprayings with thiamethoxam and imidacloprid against *A. biguttula biguttula* on okra (Pooled analysis of two seasons)

Treatments			Mean number of leaf hopper per three leaves per plant							Mean population	% reduction over UC
			Days After Sowing (DAS)								
			25	30	†31	35	40	45	50		
T_1 - ST	Thiamethoxam 30 FS	@ 3 g ai kg^{-1}	1.66^{c} (1.45)	3.00^{c} (1.85)	5.49^{b} (2.37)	8.5^{b} (2.98)	23.33^{b} (4.73)	27.83^{d} (5.24)	80.66^{bc} (8.47)	21.49	50.64
T_2 - ST	Imidacloprid 48 FS	@ 6g ai kg^{-1}	1.50^{c} (1.39)	3.5^{c} (1.95)	5.50^{b} (2.37)	8.99^{b} (3.07)	21.00^{bc} (4.55)	40.5^{b} (6.34)	78.99^{bc} (8.48)	22.85	47.52
T_3 - 2FT	Thiamethoxam 25 WDG	@ 25 g ai kg^{-1}	1.33^{c} (1.34)	2.66^{c} (1.77)	0.50^{e} (0.94)	2.33^{d} (1.66)	6.50^{e} (2.64)	13.83^{g} (3.78)	39.83^{e} (6.17)	9.56	78.04
T_4 - 2FT	Imidacloprid 70 WDG	@ 25g ai ha^{-1}	1.5^{c} (1.40)	3.00^{c} (1.86)	1.33^{d} (1.34)	3.00^{cd} (1.84)	7.33^{de} (2.79)	22.17^{e} (4.69)	73.49^{c} (8.10)	15.97	63.32
T_5 - ST+FT	Thiamethoxam 30 FS Thiamethoxam 25WDG	@ 3g ai kg^{-1} + @ 25 g ai ha^{-1}	1.66^{c} (1.45)	3.66^{c} (2.01)	0.33^{e} (0.88)	2.50^{d} (1.71)	8.50^{de} (2.99)	17.5^{f} (4.23)	44.50^{de} (6.54)	11.23	74.20
T_6 - ST+ FT	Imidacloprid 48 FS Imidacloprid 70 WDG	@ 6g ai kg^{-1} + @ 25g ai ha^{-1}	1.17^{c} (1.26)	4.16^{bc} (2.15)	1.83^{d} (1.51)	3.50^{c} (1.99)	9.17^{d} (3.11)	23.66^{de} (4.87)	51.16^{b} (7.00)	13.52	68.94
T_7 - 2 FT	Quinalphos 25 EC (Standard check)	@ 250 g ai ha^{-1}	3.00^{b} (1.84)	5.83^{b} (2.50)	3.00^{c} (1.86)	7.50^{b} (2.82)	18.66^{c} (4.26)	33.00^{c} (5.73)	81.33^{b} (8.72)	21.76	50.02
T_8 -	Untreated control		6.83^{a} (2.67)	13.49^{a} (3.70)	18.16^{a} (4.31)	22.00^{a} (4.74)	40.83^{a} (6.40)	74.83^{a} (8.57)	128.66^{a} (11.30)	43.54	
CD Value (5%)			0.31	0.35	0.31	0.26	0.37	0.44	0.55		

ST - Seed Treatment, FT - Foliar Treatment, UC - Untreated control, † - One day after spraying

Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

DAT) at 50 DAS. Control plot maintained a high population of hoppers ranging from 6.83 (25 DAS) to 128.66 (50 DAS).

Upto 30DAS, all the three methods of application ST, FT and ST+FT with thiamethoxam and imidacloprid were significantly superior to the untreated check in reducing hopper population . The treatments did not show any significant difference among them as they were equally effective. From 35 to 50 DAS, 2FT proved to be significantly most effective.

Thiamethoxam 2 FT recorded the lowest mean population (9.56) as against 43.54 hoppers per plant in untreated control thus revealing the highest reduction (78.04%) of the leafhopper population. It was followed by ST+FT thioamethoxam with 74.2 per cent reduction and ST+FT imidacloprid with 68.94 per cent population reduction. The standard check, quinalphos 2FT showed least effectiveness with 50.02 per cent population reduction. ST thiamethoxam and ST imidacloprid were on par with 2FT quinalphos.

It can thus be concluded that both thiamethoxam and imidacloprid were significantly superior to the standard check quinalphos against leafhoppers in okra. ST with both thiamethoxam and imidacloprid were equally effective in reducing the population upto 35DAS. Thereafter, 2FT thiamethoxam and ST+FT showed equal effectiveness by bringing about 74 to 78 percent reduction of hopper population upto 50DAS. ST+ FT imidacloprid was more effective than 2FT imidacloprid showing 68.94 and 63.32 per cent population reduction.

4.1.2. Toxicity of seed treatment and foliar sprays of thiamethoxam and imidacloprid to okra aphid, *Aphis gossypii*

Season -1

Findings on the impact of thiamethoxam and imidacloprid applied as seed treatment (ST), two foliar sprayings (FT) and a combination of ST followed by a foliar spraying (ST+FT) on the field population of *A. gossypii* in okra are presented in Table 5.

Seed treatment with thiamethoxam 350 FS @ 3g a.i. kg^{-1} recorded no incidence of *A. gossypii* upto 20 DAS. Thereafter, the mean density of aphid per plant showed an increase

Table 5. Toxicity of thiamethoxam and imidacloprid to field population density of *Aphis gossypii* in okra (Season- 1)

Treatments	Mean number of aphids per three leaves per plant										Mean population	% reduction over UC
	Days After Sowing (DAS)											
	15 DAS	†16 DAS	20 DAS	25 DAS	30 DAS	†31 DAS	35 DAS	40 DAS	45 DAS	50 DAS		
T_1 . ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.00	0.00	0.00	1.33^{bcd} (1.34)	9.33^{c} (3.13)	11.00^{b} (3.38)	24.00^{b} (4.94)	33.33^{b} (5.81)	24.67^{b} (5.00)	12.33^{b} (3.56)	11.59	57.80
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.00	0.00	0.66	2.33^{bc} (1.67)	9.66^{c} (3.17)	12.33^{b} (3.57)	24.33^{b} (4.97)	35.66^{b} (6.01)	27.67^{ab} (5.30)	14.00^{b} (3.76)	12.66	53.89
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	0.33	0.00	0.00	0.66^{d} (1.05)	3.00^{d} (1.85)	0.00^{d} (0.71)	0.33^{e} (0.87)	3.33^{e} (1.93)	10.66^{d} (3.33)	6.33^{c} (2.58)	2.46	91.04
T_4 - 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.33	0.00	0.00	1.33^{bcd} (1.34)	3.00^{d} (1.85)	0.00^{d} (0.71)	1.33^{de} (1.34)	5.66^{de} (2.47)	10.66^{d} (3.33)	5.00^{c} (2.34)	2.73	90.06
T_5 - ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25 g a.i ha^{-1}	0.00	0.00	0.00	1.00^{cd} (1.22)	9.00^{c} (3.04)	0.33^{d} (0.87)	0.33^{e} (0.87)	3.66^{e} (2.03)	14.00^{cd} (3.80)	11.66^{b} (3.47)	3.99	85.47
T_6 - ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.00	0.66	2.66^{b} (1.77)	11.00^{c} (3.38)	0.66^{d} (1.05)	1.66^{d} (1.46)	8.00^{d} (2.91)	16.00^{c} (4.05)	11.33^{b} (3.43)	5.19	81.09
T_7 - 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (standard check)	0.66	0.00	1.66	3.00^{b} (1.85)	18.33^{b} (4.33)	3.00^{c} (1.85)	11.00^{c} (3.38)	15.33^{c} (3.96)	32.00^{a} (5.69)	12.66^{b} (3.62)	9.76	64.46
T_8 - Untreated Control	1.33	2.33	4.00	28.33^{a} (5.35)	42.33^{a} (6.54)	55.33^{a} (7.46)	40.33^{a} (6.37)	47.33^{a} (6.91)	33.00^{a} (5.78)	20.33^{a} (4.55)	27.46	
CD Value (5%)				0.48	0.58	0.44	0.50	0.56	0.47	0.67		

ST- Seed Treatment, FT- Foliar Treatment, UC - Untreated control, † - One day after spraying

Figures in the parentheses are square root ($\sqrt{x}+0.5$) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

from 1.33 at 25 DAS to 12.33 at 50 DAS. In seed treatment with imidacloprid 600 FS @ 6 g a.i. kg^{-1}, there was no incidence of aphids till 16 DAS but from 20 DAS, the mean population per plant was found to increase from 0.66 to 14.00 at 50 DAS. The mean population density of aphids during the season in ST thiamethoxam was 11.59 while it was 12.66 in ST imidacloprid indicating a higher reduction (57.8 %) of population in ST thiamethoxam than in ST imidacloprid (53.89%) as compared to untreated control. However, ST thiamethoxam and ST imidacloprid were found to be on par throughout the season indicating that they are equally effective against *A. gossypii.*

Foliar spraying of thiamethoxam 25WG @ 25 g a.i. ha^{-1} (FT at 15 DAS) indicated no incidence of aphids till 5 DAT-1st spray (20 DAS). From 10 DAT (25 DAS), the aphid population started increasing from 0.66 to 3.00 aphids at 15DAT- 1st spray (30 DAS). After the 2nd spray at 30DAS, the population again declined to 0.00 at 1DAT-2nd spray (at 31 DAS) and then started increasing from 0.33 at 5DAT-2nd spray (35DAS) to 6.33 at 20 DAT-2nd spray (50 DAS). Imidacloprid foliar treatment (FT) also showed a similar trend wherein the population varied from 0 at 1DAT-1st spray (16 DAS) to 3.00 at15DAT - 1st spray (30 DAS) and again reduced to 0.00 at 1 DAT-2nd spray (31 DAS) and then increased to 5.00 at 20 DAT-2nd spray (50 DAS).

The combination of seed treatment followed by foliar treatment (ST+FT) with thiamethoxam recorded 0 (15 DAS) to 9.00 (30 DAS) and after foliar spraying at 30DAS, the population was reduced to 0.33 at 1 DAT (31 DAS) and then increased to 11.66 aphids per plant at 20 DAT (50 DAS). A similar trend was observed in ST+FT imidacloprid which showed 0 (15 DAS) to 11.00 aphids at 30 DAS and after the foliar spraying at 30DAS, aphid density varied from 0.66 at 1 DAT (31 DAS) to 11.33 at 20 DAT-1st spray (50 DAS). The mean population of aphids was 3.99 for thiamethoxam and 5.19 for imidacloprid.

Foliar treatment with thiamethoxam (2FT) was thus proved to be the significantly superior treatment against *A. gossypii* consistently at 25, 30, 35, 40, 45, and 50 DAS. However, it was on par with FT imidacloprid indicating their equal effectiveness with 90.06 to 91.04 percent reduction of aphid population in okra. It was followed by ST+FT thiamethoxam and imidacloprid and both revealed equal effectiveness by exhibiting 81.09 to 85.47 per cent aphid population reduction.

By only ST with imidacloprid and thiamethoxam could reduce aphid population ranging from 53.89 to 57.80 per cent.

Two foliar sprayings of the standard check quinalphos 25EC @ 250 g a.i. ha^{-1} indicated a population of 0 (1 DAT-1st spray) to 18.33 (15DAT-1st spray) and 3.00 (1 DAT-2nd spray) to 12.66 (20 DAT-2nd spray) at 50 DAS. It recorded a mean population of aphids 9.76 per plant showing 64.46 per cent reduction over control as against 27.46 aphids/plant in the untreated control.

From the above results of season 1, it can be concluded that both thiamethoxam and imidacloprid were significantly superior to the standard check quinalphos in reducing aphid population in okra. All three methods of application *viz.*, seed treatment, foliar treatment and combination of the both were found to be efficient for the population control. ST indicated 57.80 and 53.89 per cent reduction of population while 2FT resulted in 91.04 and 90.06 per cent reduction. ST+ FT combination recorded 85.47 and 81.09 per cent reduction of aphid population. Two foliar sprays of thiamethoxam recorded lowest mean population of aphids with maximum population reduction of 91.04 per cent, which equal to two foliar spraying with imidacloprid with 90.06 % reduction of aphid population over untreated control. FT with the standard check insecticide quinalphos at the recommended dosage brought about lower (64.46 per cent) reduction as compared to thiamethoxam and imidacloprid.

Season- 2

In season 2, no incidence of aphids was observed in ST with thiamethoxam upto 16 DAS (Table 6). Aphid population started increasing from 20 DAS (2.00) to 50 DAS (12.00) in ST thiamethoxam. In seed treatment with imidacloprid, no incidence was recorded up to 15 DAS and thereafter it recorded an increase from 0.33 at 16 DAS to 14.33 at 50 DAS. The mean population in ST thiamethoxam and ST imidacloprid was 19.43 and 17.59 aphids per plant.

The aphid population in two FT (15 and 30 DAS) with thiamethoxam @ 25 g a.i. ha^{-1} varied from 3.66 (1DAT-1st spray) at 16 DAS to 2.00 (15 DAT-1st spray) at 30 DAS . After the 2nd spray, aphid density ranged from 0.00 at 1 DAT-2nd spray (31 DAS) to 4.66 at 20 DAT-2nd

Table 6. Toxicity of thiamethoxam and imidacloprid to field population of *Aphis gossypii* (Season- 2)

Treatments	Mean number of aphids per three leaves										Mean population	% Reduction over UC
	Days After Sowing (DAS)											
	15	†16	20	25	30	†31	35	40	45	50		
T$_1$- ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.00	0.00	2.00^{c} (1.58)	3.00^{c} (1.85)	12.33^{c} (3.57)	17.00^{b} (4.16)	15.66^{b} (4.01)	71.00^{c} (8.45)	61.33^{b} (7.85)	12.00^{a} (3.53)	19.43	72.87
T$_2$- ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.00	0.33	2.33^{c} (1.66)	3.00^{c} (1.85)	13.33^{c} (3.71)	17.66^{b} (4.24)	19.00^{b} (4.41)	67.00^{c} (8.21)	39.00^{c} (6.28)	14.33^{a} (3.83)	17.59	75.44
T$_3$ - 2FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	24.33	3.66	0.33^{d} (0.87)	0.33^{e} (0.87)	2.00^{d} (1.55)	0.00^{d} (0.71)	0.33^{e} (0.87)	33.33^{f} (5.81)	24.33^{de} (4.97)	4.66^{b} (2.22)	9.33	86.97
T$_4$- 2FT Imidacloprid 70 WDG @ 25g a.i..ha^{-1}	32.33	3.33	0.33^{d} (0.87)	1.00^{de} (1.22)	2.00^{d} (1.55)	0.00^{d} (0.71)	2.00^{c} (1.55)	41.66^{e} (6.49)	20.00^{e} (4.53)	3.00^{b} (1.85)	10.56	85.25
T$_5$- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25 WDG @ 25 g a.i. ha^{-1}	0.00	0.00	2.33^{c} (1.67)	3.00^{c} (1.85)	12.33^{c} (3.57)	0.33^{d} (0.87)	0.66^{de} (1.05)	37.66^{ef} (6.17)	40.00^{c} (6.34)	2.66^{b} (1.76)	9.89	86.19
T$_6$- ST+ FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} Imidacloprid 70 WDG @25g a.i. ha^{-1}	0.33	0.33	2.00^{c} (1.55)	2.33^{cd} (1.67)	12.33^{c} (3.57)	0.33^{d} (0.87)	1.66^{cd} (1.46)	48.00^{d} (6.95)	26.33^{d} (5.15)	2.33^{b} (1.67)	9.59	86.61
T$_7$- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1}	16.33	3.66	21.33^{b} (4.64)	15.66^{b} (4.00)	37.33^{b} (6.14)	11.66^{c} (3.48)	16.66^{b} (4.13)	81.67^{b} (9.06)	36.00^{c} (6.04)	3.33^{b} (1.94)	24.36	65.99
T$_8$- Untreated Control	41.00	46.0	120.00^{a} (10.98)	79.33^{a} (8.93)	88.66^{a} (9.42)	74.66^{a} (8.66)	74.00^{a} (8.63)	95.66^{a} (9.80)	80.66^{a} (9.01)	16.33^{a} (4.09)	71.63	
CD Value (5%)			0.60	0.51	0.61	0.55	0.43	0.38	0.59	0.64		

ST- Seed Treatment, FT- Foliar Treatment, UC - Untreated control, † - one day after spraying

Figures in the parentheses are square root ($\sqrt{x}+0.5$) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

spray (50 DAS). In the imidacloprid foliar treatment plot, the population of aphid varied from 3.33 at 1 DAT-1st spray (16 DAS) to 2.00 at 15 DAT-1st spray (30 DAS) and 0.00 at 1DAT-2nd spray (31 DAS) to 3.00 at 20 DAT- 2nd spray (50 DAS). The mean population recorded during the season was 9.33 for thiamethoxam 2FT and 10.56 for imidacloprid 2FT.

In the combination of ST +FT with thiamethoxam, aphid population varied from 0.00 at 15 DAS to 12.33 at 30 DAS. When a foliar spray was given at 30DAS, the population varied from 0.33 (1 DAT) at 31 DAS to 2.66 at 50 DAS (20 DAT). In the combination treatment of imidacloprid, the population varied from 0.33 (15 DAS) to 12.33 (30 DAS) and after the foliar foliar spray the population varied from 0.33 (1 DAT) at 31 DAS to 2.33(20 DAT) at 50 DAS.

The population of aphids varied from 3.66 (1 DAT-1st spray) at 16 DAS to 37.33 (15 DAT-1st spray) at 30 DAS and 11.66 (1 DAT-2nd spray) at 31 DAS to 3.33 (20 DAT-2nd spray) at 50 DAS in the standard recommended check quinalphos spray.

During the second season also, 2 FT thiamethoxam continued to record the lowest mean aphid population (9.33) with a highest population reduction of 86.97 per cent. Imidacloprid 2 FT also proved effective with 85.25 percent reduction of aphid population. ST+FT imidacloprid and ST +FT thiamethoxam were also equally effective with 86.61 per cent and 86.19 per cent reduction over untreated control. Seed treatment with thiamethoxam and imidacloprid recorded only 72.87 per cent and 75.44 per cent reduction of population.

Pooled analysis of data of two seasons

Data of two seasons were pooled and statistically analyzed to know the overall impact of thiamethoxam and imidacloprid on the field population density of aphids in okra and the results are presented in Table 7. Since the aphid population in the initial stages from 15 DAS to 20 DAS were very low and almost zero, pooled analysis was done for the data from 25 DAS to 50 DAS.

The mean aphid population in different treatments varied from 6.38 (2FT thiamethoxam) to 22.02 (ST thiamethoxam) as against 55.44 in the untreated control.

Table 7. Toxicity of thiamethoxam and imidacloprid to *Aphis gossypii* in okra (Pooled analysis of two seasons)

Treatments	Mean no.of aphids per three leaves							Mean population	% reduction over UC
	Days After Sowing (DAS)								
	25	30	†31	35	40	45	50		
T_1 - ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	2.16^{cd} (1.60)	10.83^{c} (3.35)	14.00^{b} (3.78)	19.83^{b} (4.48)	52.16^{b} (7.31)	43.00^{b} (6.43)	12.16^{a} (3.55)	22.02	60.20
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	2.66^{c} (1.77)	11.50^{c} (3.45)	14.99^{b} (3.91)	21.66^{b} (4.69)	51.33^{b} (7.11)	33.33^{c} (5.79)	14.16^{a} (3.80)	21.37	61.45
T_3 - 2 FT Thiamethoxam- 25WDG @ 25 g a.i. kg^{-1}	0.50^{e} (0.97)	2.50^{d} (1.71)	0.00^{d} (0.71)	0.33^{e} (0.88)	18.33^{f} (3.87)	17.5^{f} (4.16)	5.50^{bc} (2.40)	6.38	88.49
T_4 - 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	1.17^{de} (1.28)	2.50^{d} (1.71)	0.00^{d} (0.71)	1.66^{d} (1.45)	23.66^{e} (4.48)	15.33^{f} (3.93)	4.00^{c} (2.10)	6.90	87.55
T_5 - ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25 g a.i. ha^{-1}	1.67^{cd} (1.54)	10.66^{c} (3.31)	0.33^{d} (0.88)	0.50^{e} (0.97)	20.66^{f} (4.11)	27.00^{d} (5.07)	7.16^{b} (2.62)	9.71	82.48
T_6 - ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	2.50^{c} (1.73)	11.66^{c} (3.48)	0.50^{d} (0.97)	1.66^{d} (1.46)	28.00^{d} (4.93)	21.17^{e} (4.61)	6.83^{bc} (2.56)	10.33	81.36
T_7 - 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1}	9.33^{b} (2.93)	27.83^{b} (5.24)	7.33^{c} (2.67)	13.83^{c} (3.76)	48.5^{c} (6.51)	34.00^{c} (5.87)	7.99^{b} (2.78)	21.25	61.67
T_8 - Untreated Control	53.83^{a} (7.14)	65.50^{a} (7.99)	64.99^{a} (8.07)	57.16^{a} (7.51)	71.5^{a} (8.36)	56.83^{a} (7.40)	18.33^{a} (3.57)	55.44	
CD value (5%)	0.33	0.41	0.33	0.31	0.33	0.35	0.45		

ST - Seed Treatment, FT- Foliar Treatment, UC - Untreated control, † - one day after spraying

Figures in the parentheses are square root ($\sqrt{x}+0.5$) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

In the plot of seed treatment with thiamethoxam, the aphid population varied from 2.16 at 25 DAS to 12.16 at 50 DAS with a mean of 22.02 aphids/plant. Seed treatment with imidacloprid recorded 2.66 (25 DAS) to 14.16 (50 DAS) aphids per plant with a mean of 21.37 aphids per plant resulting in 60.20 to 61.45 percent reduction over control.

Aphid population in foliar treatment with thiamethoxam (2FT) varied from 0.50 (10 DAT- 1 st spray) at 25 DAS to 2.50 (15 DAT- 1st spray) at 30 DAS and 0.00 (1 DAT-2nd spray) at 31 DAS to 5.50 (20 DAT- 2nd spray) at 50 DAS. This treatment maintained lowest mean population of aphids (6.38) over the two seasons. This treatment was followed by foliar treatment with imidacloprid, where the population of aphids varied from 1.17 (10 DAT-1st spray) at 25 DAT to 2.50 (15 DAT- 1st spray) at 30 DAS and 0.00 (1DAT-2nd spray) at 31 DAS to 4.00 (20 DAT-2nd spray) at 50 DAS with a mean of 6.90 aphids per plant. Two foliar sprayings of both thiamethoxam and imidacloprid indicated the highest reduction (88%) of aphid population.

In the combination of ST+FT thiamethoxam, the population of aphids varied from 1.67 at 25 DAS to 10.66 at 30 DAS and 0.33 (1 day after spray) at31 DAS to 7.16 (20 days after spray) at 50 DAS with a mean population of 9.71 aphids per plant. Combination treatment with imidacloprid recorded 2.50 (25 DAS) to 11.66 (30 DAS) and after the foliar spray the population varied from 0.50 (31DAS) to 6.83 (50 DAS) with a mean population of 10.33. Both thiamethoxam and imidacloprid as ST+FT proved to be equally by causing 81 to 82 percent reduction of aphid as compared to control.

Foliar spraying with quinalphos recorded 9.33 (10 DAT-1st spray) at 25 DAS to 7.33 (15 DAT-1st spray) aphids at 30 DAS and from 7.33 (1DAT-2nd spray) at 31 DAS to 7.99 (20DAT-2nd spray) at 50 DAS and it showed a mean of 21.25 aphids per plant. The population reduction by ST with thiamethoxam and imidacloprid was found to be equal to two foliar sprayings of quinalphos.

At 25 DAS, all the treatments ST, 2FT and ST+FT with thiamethoxam and imidacloprid were significantly superior to untreated control and foliar treatment with quinalphos.

From 35 to 50 DAS, 2FT thiamethoxam and imidacloprid were equally effective in controlling aphid population with 88.49 per cent and 87.55 per cent reduction over untreated control. This was followed by combination treatment of thiamethoxam ST+FT and imidacloprid ST+FT with 82.48 per cent and 81.36 per cent reduction of population over untreated control. The standard recommended check quinalphos 2FT was significantly less effective with only 61.67 per cent reduction of population as compared to 88.49 per cent in thiamethoxam and 87.55 per cent reduction in imidacloprid.

It is thus proved from the above findings that both thiamethoxam and imidacloprid were significantly superior over the standard check quinalphos. Seed treatment with thiamethoxam and imidacloprid can protect the crop upto 25-30 DAS. Thereafter, foliar spraying with thiamethoxam or imidacloprid was equally effective in controlling *A.gossypii.*

4.1.3 Toxicity of seed treatment and foliar sprayings with thiamethoxam and imidacloprid on *Bemisia tabaci*

(Season- 1)

Results on the efficacy of thiamethoxam and imidacloprid applied as seed treatment (ST) and two foliar sprayings (2FT) and seed treatment followed by foliar spraying (ST+FT) against field population of white flies in okra are presented in Table 8.

The incidence of white flies in treatments as well as in untreated control was very low during the season. Hence, no statistical anlaysis of the data was carried out. Seed treatment with thiamethoxam @ 3g a.i. kg^{-1} recorded no attack by whitefly upto 15 DAS. The mean population in ST of thiamethoxam and imidacloprid was found to be 0.19 and 0.14. Imidacloprid FT and ST+FT showed lowest population (0.05) among all treatments. Imidacloprid showed lower whitefly population than thiamethoxam in okra.

In the combination treatments of ST+FT also imidacloprid recorded a lower population (0.05) than thiamethoxam (0.15). Imidacloprid, by all the three methods of application, thus proved to be more effective than thiamethoxam against *B.tabaci.* Next to imidacloprid,

Table 8. Effect of thiamethoxam and imidacloprid on *Bemisia tabaci* on okra (Season - 1)

Treatments		Mean number of whiteflies per three leaves							Mean population
		Days After Sowing (DAS)							
		15	†16	20	25	30	†31	35	
T_1- ST	Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.00	0.33	0.33	0.33	0.33	0.00	0.00	0.19
T_2 - ST	Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.33	0.33	0.00	0.00	0.00	0.00	0.33	0.14
T_3 - 2 FT	Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	1.00	0.00	0.00	0.00	0.33	0.00	0.33	0.24
T_4- 2FT	Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.05
T_5- ST+FT	Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam25WDG @ 25 g a.i. ha^{-1}	0.00	0.66	0.00	0.00	0.00	0.33	0.33	0.15
T_6- ST+FT	Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.05
T_7- 2FT	Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.09
T_8-	Untreated Control	0.66	1.33	0.66	0.00	1.00	0.66	0.33	0.66

ST - Seed Treatment, FT - Foliar Treatment, † - One day after spraying quinalphos recorded the lowest population (0.09) as compared to the highest population in untreated control (0.66 whiteflies/ plant).

From the above results, it can be concluded that FT imidacloprid or combination of imidacloprid ST+FT was effective with lowest whitefly population as compared to the untreated control. This was followed by FT quinalphos and ST imidacloprid.

Season 2

In season 2, the population was very low till 31 DAS and hence statistical analysis was done for the data from 35 DAS only (Table 9). The treatments showed no statistical significance. However, all the insecticide treatments reduced white fly population as compared to untreated control.

No incidence of whiteflies was observed in ST with thiamethoxam and ST imidacloprid upto 15 DAS. Thereafter, the population slowly increased ranging from 0.33 at 16 DAS to 2.00 at 50 DAS. But in seed treatment plot with imidacloprid no incidence was recorded up to 25 DAS. The mean population in ST imidacloprid and ST thiamethoxam was 0.89 and 1.39 whiteflies per plant.

Two FT (15 and 30 DAS) imidacloprid recorded a lower mean population (0.39) as compared to two FT thiamethoxam (0.56). Foliar spraying with quinalphos recorded 0.46 as compared to 1.96 in untreated control. The different treatments showed no significant difference on whitefly population. However, during the second season also, 2FT imidacloprid continued to be more effective as it record the lowest (0.39) mean whitefly population which was followed by 2 FT quinalphos.

4.1.4. Effect of thiamethoxam and imidacloprid on the damage caused by *Sylepta derogata*

Results on the effect of thiamethoxam and imidacloprid applied as seed treatment, foliar treatement as well as a combination of both applications against *Sylepta derogata* are given in Table 10. The damage was observed to be very low in both the seasons. Hence only mean per cent leaf damage per plant was worked out.

Table 9. Impact of thiamethoxam and imidacloprid on the incidence *Bemisia tabaci* (Season 2)

Treatments	Mean no.of whiteflies per three leaves										Mean population
	Days After Sowing (DAS)										
	15	†16	20	25	30	†31	35	40	45	50	
T$_1$ - ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.00	0.33	0.66	1.33	0.33	1.66	1.00 (1.17)	3.66 (2.02)	3.00 (1.87)	2.00^{b} (1.56)	1.39
T$_2$ - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.00	0.00	0.00	0.00	0.33	1.33	1.00 (1.17)	2.33 (1.67)	2.66 (1.76)	1.33^{bc} (1.34)	0.89
T$_3$ - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	0.33	0.00	0.00	0.00	0.33	0.00	0.33 (0.88)	2.66 (1.74)	1.33 (1.34)	0.66^{cd} (1.05)	0.56
T$_4$ - 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.66	0.00	0.00	0.00	0.33	0.00	0.00 (0.71)	1.33 (1.34)	1.33 (1.34)	0.33^{d} (0.88)	0.39
T$_5$ - ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam25WDG @ 25 g a.i. ha^{-1}	0.00	0.00	0.33	0.00	0.33	0.00	0.33 (0.88)	1.66 (1.46)	3.00 (1.86)	2.66^{ab} (1.77)	0.83
T$_6$ - ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.66	1.00	1.66	0.33	0.00	1.33 (1.34)	2.33 (1.64)	2.33 (1.64)	2.33^{ab} (1.67)	1.19
T$_7$ - 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	0.33	0.00	0.33	0.00	0.00	0.00	1.33 (1.34)	1.00 (1.22)	1.33 (1.34)	0.33^{d} (0.88)	0.46
T$_8$ - Untreated control	2.00	1.00	1.33	1.66	0.33	1.66	1.33 (1.34)	3.00 (1.81)	3.33 (1.93)	4.00^{a} (2.11)	1.96
CD Value (5%)							NS	NS	NS	0.42	

ST - Seed Treatment, FT - Foliar Treatment, UC - Untreated control, NS - Non Significant, † - One day after spraying

Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

In the first season, the mean per cent damage by *S.derogata* per plant varied from 0.66 in 2 FT imidacloprid to 1.99 in ST thiamethoxam as against 2.39 per cent in untreated control. Combination treatment caused 1.59 per cent and 1.73 per cent for thiamethoxam and imidacloprid respectively.

In the second season, 2FT imidacloprid and ST thiamethoxam recorded no incidence of damage by *S. derogata*. ST+FT imidacloprid showed highest damage (2.04 %) as compared to 7.05 per cent in the untreated control. In the ST plots the damage was 0.00 for thiamethoxam and 1.45 per cent for imidacloprid. Foliar treatment with thiamethoxam caused 0.71 per cent damage and for imidacloprid it was 0.00 per cent. Combination treatment caused 1.26 per cent and 2.04 per cent damage for thiamethoxam and imidacloprid. Foliar treatment quinalphos produced 0.79 per cent damage per plant.

From the two seasons it can be concluded that two foliar treatments with imidacloprid effectively reduced leaf roller damage.

Table 10. Toxicity of thiamethoxam and imidacloprid against *Sylepta derogata*

Treatments			Mean per cent damage per plant	
			Season 1	Season 2
T_1 - ST	Thiamethoxam 30 FS	@ 3 g a.i. kg^{-1}	†1.99	0.00
T_2 - ST	Imidacloprid 48 FS	@ 6 g a.i. kg^{-1}	1.53	1.45
T_3 - 2 FT	Thiamethoxam 25WDG	@ 25 g a.i. kg^{-1}	1.06	0.71
T_4 - 2FT	Imidacloprid 70 WDG	@ 25g a.i. ha^{-1}	0.66	0.00
T_5 - ST+FT	Thiamethoxam 30 FS Thiamethoxam 25WDG	@ 3g a.i. kg^{-1} + @ 25 g a.i. ha^{-1}	1.59	1.26
T_6 - ST+FT	Imidacloprid 48 FS Imidacloprid 70 WDG	@ 6g a.i. kg^{-1} + @ 25g a.i. ha^{-1}	1.73	2.04
T_7 - 2FT	Quinalphos 25 EC (Standard check)	@ 250 g a.i. ha^{-1}	0.79	0. 79
T_8 -	Untreated control		2.39	7.05

ST - Seed Treatment, FT - Foliar Treatment.

† - Mean of five observations taken at 5 days interval starting from 30 days after sowing.

4.1.5 Toxicity of thiamethoxam and imidacloprid to shoot borer *Earias vitella*

Season-1

Results on the effect of thiamethoxam and imidacloprid on shoot damage by *E.vitella* are presented in Table 11.

In the first season at 35 DAS there was no damage incidence by shoot borer. The different treatments showed significant effect only at 40 DAS wherein the damage varied from 8.33 to 30.55 percent.

At 40DAS, seed treatment (ST) with thiamethoxam @ 3g a.i. kg^{-1} and imidacloprid @ 6 g a.i. kg^{-1} indicated no significant difference in the damage of *E.vitella.* These recorded 23.33 and 30.55 per cent damage as compared to 30.55 per cent in the untreated control. But the two foliar sprayings (2 FT) with thiamethoxam @ 25 g a.i. ha^{-1} at 15 and 30 DAS significantly reduced the damage (8.33 per cent) at 40 DAS (10 DAT- 2nd spray). However, it was on par with 2FT imidacloprid. All the other treatments, including the standard check quinalphos (30.55 per cent) were on par with the untreated control indicating no significant effect.

At 45 DAS, there were no incidence by shoot borer except for ST imidacloprid were the damage was 5.33 as compared to 30.55 per cent in untreated control.

The mean damage per plant over the season varied from 4.16 for FT thiamethoxam to 17.94 per cent for ST imidacloprid and FT quinalphos as against 30.55 per cent in untreated control. During the season, 2FT thiamethoxam recorded the lowest mean damage (4.16) followed by 2FT imidacloprid (5.55 per cent) as against 30.55 per cent damage in untreated control. Combination of seed treatment followed by foliar treatment (ST+FT) thiamethoxam and imidacloprid caused 11.66 and 13.05 per cent damage respectively. Standard check insecticide quinalphos showed 17.94 per cent damage.

Table 11. Influence of thiamethoxam and imidacloprid on shoot borer *Earias vitella*

Treatments	Mean percent shoot damage per plant						Mean damage (%)	
	Days After Sowing (DAS)							
	35		40		45			
	S1	S2	S1	S2	S1	S2	S1	S2
T_1 - ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	-	20.33	23.33^{ab} (4.87)	0.00	0.00	0.00	10.16	6.77
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	-	0.00	30.55^{a} (5.56)	0.00	5.33	31.94	17.94	10.64
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	-	0.00	8.33^{c} (2.15)	0.00	0.00	0.00	4.16	0.00
T_4 - 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	-	0.00	11.11^{bc} (2.41)	0.00	0.00	44.66	5.55	14.88
T_5 - ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam25WDG @ 25 g a.i. ha^{-1}	-	0.00	23.33^{ab} (4.87)	0.00	0.00	0.00	11.66	0.00
T_6 - ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	-	0.00	26.11^{a} (5.13)	0.00	0.00	8.33	13.05	2.77
T_7 - 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	-	0.00	30.55^{a} (5.56)	0.00	0.00	0.00	17.94	0.00
T_8 - Untreated Control	-	26.11	30.55^{a} (5.56)	19.66	30.55	45.00	30.55	30.26
CD Value (5 %)			2.49					

S1- Season 1, S2 - Season 2, ST - Seed Treatment, FT - Foliar Treatment
Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

The data thus revealed that among the treatments, 2FT thiamethoxam was the most effective followed by 2FT imidacloprid in reducing the damage by shoot borer

Season 2

Incidence of shoot borer damage was very low in the 2nd season also and so no statistical analysis was done (Table 11).

Shoot borer damage varied from 26.11 (35 DAS) to 45.00 per cent (45DAS) in the untreated control but there was no damage in treatments except 20.33, 31.94 , 44.66 and 8.33 percent in ST thiamethoxam (35DAS), ST imidacloprid (45DAS), 2FT imidacloprid (45DAS) and ST+FT imidacloprid respectively. Thiamethoxam (ST, ST+FT, 2 FT) and quinalphos recorded the lowest mean damage.

From the both seasons data FT thiamethoxam was found effective in controlling the damage by shoot borer *E. vitella.*

4.1.6 Toxicity of thiamethoxam and imidacloprid on fruit borer

Season 1

Results on the influence of thiamethoxam applied as seed treatment and foliar treatment against fruit damage by *E.vitella* are presented in Table 12. All insecticide treatments significantly reduced the damage of fruits in terms of number as well as by weight as compared to the untreated control. Two FT thiamethoxam significantly reduced the number of damaged fruits ie. 4.95 per cent. Two FT imidacoprid showed equal effectiveness with 2 FT thiamethoxam as they were on par. All the other treatments, including the standard check quinalphos, were on par indicating 7.91 to 26.37 per cent damage in fruits in terms of number.

Fruit damage on weight basis also followed the same trend. Two FT thiamethoxam significantly reduced the fruit damage by *E.vitella* as revealed by the lowest fruit damage (2.67 %) as compared to 12.74 per cent in untreated control. ST+FT thiamethoxam and imidacloprid caused 4.32 to 6.87 per cent damage as against the standard check two FT quinalphos (5.94 %).

Table 12. Influence of seed and foliar treatment of thiamethoxam and imidacloprid on fruit damage by *Earias vitella*

Treatments	Damaged fruits per plant (%)							
	Number basis				Weight basis (g)			
	S1	S2	Pooled mean	% reduction over UC	S1	S2	Pooled mean	% reduction over UC
T_1- ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	9.68^{bcd} (3.17)	14.34^{ab} (3.83)	12.01^{bcd} (3.50)	52.49	5.03^{bcd} (2.34)	7.50^{ab} (2.81)	6.26^{bcde} (2.57)	53.45
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	18.29^{ab} (4.29)	14.62^{bc} (3.72)	16.46^{b} (4.01)	34.88	8.16^{ab} (2.93)	14.57^{a} (3.58)	11.37^{ab} (3.26)	15.46
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	4.95^{d} (2.31)	6.15^{c} (2.51)	5.55^{fg} (2.41)	78.04	2.67^{d} (1.77)	3.16^{b} (1.87)	2.92^{fg} (1.82)	78.29
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	8.36^{cd} (2.92)	8.08^{bc} (2.89)	8.22^{defg} (2.91)	67.48	4.14^{cd} (2.12)	4.18^{b} (2.14)	4.16^{cdefg} (2.13)	69.07
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam25WDG @ 25 g a.i. ha^{-1}	13.56^{bc} (3.73)	13.29^{bc} (3.65)	13.43^{bc} (3.69)	46.87	6.87^{bc} (2.71)	7.16^{ab} (2.73)	7.02^{abc} (2.72)	47.81
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	7.91^{cd} (2.77)	12.12^{bc} (3.48)	10.01^{cdef} (3.13)	60.40	4.32^{cd} (2.13)	6.25^{ab} (2.55)	5.28^{cdef} (2.34)	60.74
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	11.31^{bcd} (3.41)	12.75^{bc} (3.56)	12.03^{bcde} (3.49)	52.41	5.94^{bcd} (2.52)	6.73^{ab} (2.64)	6.33^{bcd} (2.57)	52.93
T_8- Untreated Control	26.37^{a} (5.17)	24.23^{a} (4.95)	25.28^{a} (5.06)		12.74^{a} (3.61)	14.16^{a} (3.82)	13.45^{a} (3.71)	
CD Value (5 %)	1.09	1.15	0.78		0.79	1.14	0.68	

S1 - Season 1, S2 - Season 2, ST - Seed Treatment, FT - Foliar Treatment

Figures in the parentheses are square root ($\sqrt{x}+0.5$) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

Season 2

In the second season also similar trend was observed (Table 12). Per cent fruit damage in number as well as weight by *E.vitella* was significantly less in 2 FT thiamethoxam. That treatment caused 6.15 per cent damage in number basis and 3.16 per loss in weight as against 24.23 per cent loss in number and 14.16 per cent loss in terms of weight in the untreated control. This treatment was on par with 2FT imidacloprid, ST+FT thiamethoxam, ST+FT imidacloprid and 2FT quinalphos.

Pooled analysis

Pooled analysis of the two season's data (Table 12) revealed that 2FT thiamethoxam was significantly superior over all other treatments in reducing fruit damage by *E.vitella* in terms of both fruit number and weight. Two FT thiamethoxam recorded the lowest damage of 5.55 per cent fruits per plant as against 25.28 per cent damaged fruits per plant in the untreated control indicating the highest (78.04 per cent) damage reduction of number and weight (78.29%) of damaged fruits . However, it was found to be on par with 2FT imidacloprid showing 67.5 to 69 per cent reduction of fruit damage.

Combination treatment (ST+FT) of imidacloprid and thiamethoxam reduced 60 per cent damage in fruit number and 47 per cent damage in weight. Seed treatment with imidacloprid reduced 34.88 per cent damage in terms of number and 15.46 per cent reduction of damage in weight over untreated control. Seed treatment with thiamethoxam plots reduced 52.49 per cent and 15.46 to 53.45 per cent fruit damage reduction.

4.2. Safety of thiamethoxam and imidacloprid to natural enemies

Predators like occinellids, spiders and others were observed in the experimental plots.

4.2.1. Coccinellids

Results on the effect of thiamethoxam and imidacloprid on the incidence of coccinellid population in different treatments in okra field are presented in Table 13. Four major species of coccinellid observed in okra field were *Cheilomenes sexmaculata, Coccinella transversalis, Micraspis discolor and Pseudaspidimerus sp* (Plate 5)

Season 1

In the first season, the untreated control maintained a highest mean population of coccinellid per plant (2.66). But ST+FT imidacloprid showed no coccinellids and 2FT imidacloprid recorded a lower mean population of 0.55 per plant. Seed treatment with imidacloprid also showed lesser coccinellids than ST thiamethoxam. Among the insecticide treatments, highest number of coccinellids was observed in 2FT thiamethoxam (1.77). Followed by ST thiamethoxam and ST + FT thiamethoxam.

Season 2

In the second season, highest mean population per plant was recorded for untreated control (3.77), which was followed by ST thiamethoxam (2.66). Seed treatment imidacloprid recorded 1.44 coccinellids per plant. In the foliar treatments, in both thiamethoxam and imidacloprid the population was 1.55. In the combination treatment ST+FT, thiamethoxam recored 1.22 and for imidacloprid it was 0.88. Foliar treatment of quinalphos recored 1.33 coccinellids per plant. In both seasons, thiamethoxam treatments recorded a higher coccinellid population than imidacloprid treatments.

4.2.2. Spiders

Results on the safety of thiamethoxam and imidacloprid to the spider population in the first season are presented in Table 14. Spider population was less in Season 1.

In season 1, Two FT thiamethoxam recorded the highest spider population (0.77) followed by ST imidacloprid, as compared to 0.66 in untreated control. Combination treatment of thiamethoxam and 2 FT imidacloprid showed same population (0.22). Lowest population was observed in ST+FT imidacloprid and 2 FT quinalphos (0.11).

Season 2, recorded a higher population ranging from 0.66 in ST thiamethoxam to 2.11 in 2FT imidacloprid and combination treatment of thiamethoxam as compared to 2.99 in untreated control.

The spider population was not significantly different among the treatments in both seasons

Table 13. Safety of thiamethoxam and imidacloprid to coccinellid population in okra

Treatments	Mean no. of coccinellids per plant							
	Days After Sowing							
	30		40		50		Mean	
	S1	S2	S1	S2	S1	S2	S1	S2
T_1- ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.66	2.66	0.00	2.00	2.66	3.33	1.11	2.66
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.00	0.00	0.00	3.33	2.66	0.99	0.88	1.44
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	0.66	0.00	0.99	2.66	3.66	2.00	1.77	1.55
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.00	0.00	1.33	1.66	3.33	0.55	1.55
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25 g a.i. ha^{-1}	0.00	0.00	0.00	1.66	2.00	2.00	0.66	1.22
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.00	0.00	1.99	0.00	0.66	0.00	0.88
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	0.00	0.00	0.00	2.00	0.66	2.00	0.22	1.33
T_8- Untreated control	0.99	1.99	4.33	5.33	2.66	4.00	2.66	3.77

S1 - season 1, S2 - season 2

ST - Seed Treatment, FT - Foliar Treatment

Table14. Impact of thiamethoxam and imidacloprid on incidence of spiders in okra field

Treatments	Mean spider population per plant							
	Days After Sowing						Mean	
	20		40		60			
	S1	S2	S1	S2	S1	S2	S1	S2
T_1. ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.00	0.00	0.00	2.00	0.67	2.00	0.22 (66.66)	0.66 (77.92)
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.00	0.33	0.00	1.33	1.00	3.66	0.33 (50.00)	1.77 (40.80)
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	0.33	0.00	0.66	1.33	1.333	2.66	0.77 (16.66)	1.33 (55.52)
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.66	0.00	1.33	0.67	4.33	0.22 (66.66)	2.11 (29.43)
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25 g a.i. ha^{-1}	0.00	0.33	0.00	2.33	0.67	2.66	0.22 (66.66)	2.11 (29.43)
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.00	0.33	0.00	2.00	0.33	4.00	0.11 (83.33)	1.55 (48.16)
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	0.00	0.00	0.00	2.00	0.33	3.66	0.11 (83.33)	1.88 (37.12)
T_8- Untreated Control	0.00	2.00	0.33	2.33	1.67	4.66	0.66	2.99

S 1- Season 1, S 2-Season 2, ST- Seed treatment, FT - Foliar Treatment

Values in the parentheses are percent increase or decrease of spider over untreated control

4.2.3. Safety of thiamethoxam and imidacloprid against other predators

Results on the effect of thiamethoxam and imidacloprid on other predators *viz.* rove beetle (*Paederus* sp.), chrysoperla (*Chrysoperla carnea*) and syrphids population are presented in Table 15.

In the first season the mean population of natural enemies per plant varied from 0.07 to 0.25. Combination treatment of imidacloprid maintained high population of 0.25. This was followed by untreated control, where the population of natural enemies was 0.17 numbers. In the ST thiamethoxam the population was 0.17 and for imidacloprid it was 0.07 per plant. In the foliar treatment the mean population was 0.08 for both FT thiamethoxam and FT Imidacloprid. In the combination treatment ST +FT the population was 0.08 for thiamethoxam and 0.249 for imidaclorid. FT quinalphos recorded 0.08 population of natural enemies.

In the second season also highest population was recorded in ST thiamethoxam 1.42 which was followed by untreated control 1.33. Seed treatment imidacloprid recorded 0.08 natural enemies per plant. In the foliar treatment the population in thiamethoxam was 0.249 and for imidacloprid it was 0.42. In the combination treatment ST+FT, thiamethoxam recored 0.25 and for imidacloprid it was 0.08. Foliar treatment of quinalphos recored 0.00 natural enemies.

From the above findings it can be concluded that seed treatment with thiamethoxam is less deleterious to the other natural enemies population.

Table 15. Safety of thiamethoxam and thiamethoxam against other natural enemies

Treatments	Mean population of other natural enemies	
	S 1	S 2
T_1- ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	0.17	1.42
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	0.07	0.08
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	0.08	0.25
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.08	0.42
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25 g a.i. ha^{-1}	0.08	0.25
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	0.25	0.08
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	0.08	0.00
T_8- Untreated Control	0.17	1.33

S1- Season 1, S2 – Season 2ST- Seed Treatment, FT- Foliar Treatment

4.3. Influence of thiamethoxam and imidacloprid on growth parameters of okra

Results on the influence of thiamethoxam and imidacloprid on the plant growth parameters of okra are explained below.

4.3.1. Height of the plant

In season 1, all the insecticide treatments significantly increased the plant height (Plate 8) as compared to control (Table 16). The combination treatment of thiamethoxam ST+FT recorded the maximum height (99.00 cm) and were on par with 2FT thiamethoxam. This was followed by all other treatments, including the standard check quinalphos, and they were on par.

In the second season (Table 16) also maximum height was observed in FT thiamethoxam (99.60) and it was on par with combination treatment ST+FT imidacloprid. Plant height was significantly low in FT quinalphos (67 cm) and it was on par with untreated control.

Pooled analysis data of the two seasons revealed that FT thiamethoxam was significantly superior in increasing plant height (98.62cm) indicating 46.96 per cent increase in height over control and it was on par with combination ST+FT imidacloprid (91.4 cm) with 36.21 per cent height increase over control. Seed treatment with thiamethoxam and imidacloprid showed 27 to 31 per cent increase in plant height and which were on par. Combination, ST + FT thiamethoxam and imidacloprid brought about 34.5 and 36.2 per cent increase in height of okra plants. But quinalphos showed 11.6 per cent increase also.

Table 16. Impact of thiamethoxam and imidacloprid on vegetative characters of okra

Treatment	Height of plant (cm) at 60 DAS				No.of leaves per plant at 60 DAS			
	S 1	S 2	Pooled mean	% increase over UC	S 1	S 2	Pooled mean	% increase over UC
T_1. ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	85.70^{b}	84.80^{c}	85.25^{bc} (9.25)	27.05	44.20^{c}	29.10^{abc}	36.65^{c} (6.06)	32.31
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	87.50^{b}	88.20^{bc}	87.85^{bc} (9.40)	30.92	37.40^{d}	24.40^{cd}	30.90^{d} (5.57)	11.55
T_3 - 2 FT Thiamethoxam 25WDG @ 25 g a.i. kg^{-1}	97.63^{a}	99.60^{a}	98.62^{a} (9.95)	46.96	48.50^{b}	33.50^{a}	41.00^{a} (6.41)	48.01
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	84.50^{b}	82.30^{c}	83.4^{c} (9.16)	24.29	42.60^{c}	32.00^{ab}	37.30^{bc} (6.12)	34.65
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i kg^{-1}+ Thiamethoxam 25WDG @ 25 g a.i. ha^{-1}	99.00^{a}	81.50^{c}	90.25^{bc} (9.51)	34.50	42.70^{c}	24.20^{cd}	33.45^{d} (5.77)	20.76
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1}+ Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	85.70^{b}	97.10^{ab}	91.4^{ab} (9.58)	36.21	54.50^{a}	28.10^{bc}	41.3^{ab} (6.38)	49.09
T_7- 2FT Quinalphos 25 EC @ 250g a.i. ha^{-1} (Standard check)	82.80^{b}	67.00^{d}	74.9^{d} (8.67)	11.62	41.60^{c}	22.60^{d}	32.1^{d} (5.65)	15.88
T_8- Untreated Control	68.90^{c}	65.30^{d}	67.1^{e} (8.21)		34.40	21.00^{d}	27.7^{e} (5.27)	
CD Value	9.59	10.29	0.37		4.21	4.79	0.26	

S1 - Season 1, S2 - Season 2

ST- Seed Treatment, FT- Foliar Treatment, UC - Untreated control, DAS – Days After Sowing

Figures in the parenthesis are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT ($P= 0.05$)

4.3.2. Leaves per plant

Findings on the effect of thiamethoxam and imidacloprid on the number of leaves per plant are elucidated in Table 16. Combination treatment ST+FT imidacloprid significantly increased the leaves and was superior to all other treatments (54.50 leaves). This treatment was followed by FT thiamethoxam which produced 48.50 leaves per plant. Seed treatment with imidacloprid recorded the lowest number of leaves (37.40) among the insecticide treatments.

In the second season (Table 16), FT thiamethoxam indicated higher no.of leaves 33.50 per plant and it was on par with 2 FT imidacloprid. All other treatments of thiamethoxam and imidacloprid showed no significant difference in the number of leaves. Foliar treatment quinalphos recorded lowest number of leaves and was on par with control (21.00).

Pooled analysis of the two seasons data revealed that FT thiamethoxam (41.00) and ST+FT imidacloprid (41.3) produced significantly higher number of leaves over all other treatments. These treatments caused 48 – 49 per cent increase in leaves. ST thiamethoxam indicated 32.31 per cent increase of leaf production while ST imidacloprid showed the lowest (11.55 %) increase over untreated control. FT quinalphos yielded 15.88 per cent increase in leaf production. FT thiamethoxam produced 48.01% more leaves compared to untreated control.

4.3.3. Influence of thiamethoxam and imidacloprid on flower initiation

Results on the influence of thiamethoxam and imidacloprid on the number of days required for flower initiation in okra during the two seasons are presented in Table 17. ST thiamethoxam (34.33 days), ST imidacloprid (35 days) and combination treatment ST+FT thiamethoxam (35.33 days) and ST+FT imidacloprid (35.33) significantly reduced the number of days for flower initiation in okra and theywere on par. Two FT thiamethoxam, 2FT imidacloprid and quinalphos, the standard check, and the untreated control did not show any significant difference in the period (40) for flower initiation.

In season 2, ST thiamethoxam (34.66 days) and ST imidacloprid (34.33) exhibited flower initiation in 34 days as against 40 days in untreated control indicating their significant effect in reducing the period for flower initiation. This was followed by ST+FT

Plate 8. Treatment effect of neonicotinoid on plant height

8a. Untreated control

8b.Neonicotinoid insecticide treated plot

thiamethoxam and imidacloprid (37 days). Foliar spraying treatments of all insecticides recorded a longer period (40 days) for flower initiation on par with control.

Pooled analysis of the two season data revealed that days required for flower initiation in okra was significantly reduced by ST thiamethoxam (34.50) and ST imidacloprid (34.67) as compared to 40 days in untreated control. Both were on par revealing 15.15 per cent and 14.75 per cent reduction in no.of days to flower initiation. ST+FT thiamethoxam and imidacloprid indicated 10.7 to 11.5 per cent reduction in the no.of days for flower initiation.Quinalphos showed no significant effect on flower initiation.

4.4.4. Influence of thiamethoxam and imidacloprid on flower production

Effect of thiamethoxam and imidacloprid on the number of flowers per plant in the first season is furnished in Table 17. In the season 1, two FT imidacloprid recorded highest number of flowers (5.00) and it was on par with 2FT thiamethoxam (4.66) followed by ST thiamethoxam (4.00). ST+FT thiamethoxam, ST+FT imidacloprid. Quinalphos 2FT showed no significant difference in flowers as compared to control.

In the second season, both FT thiamethoxam and FT imidacloprid showed highest number of flowers (4.33) as against 1.7 flowers in untreated control. It was followed by ST imidacloprid (3.33). ST+FT imidacloprid, ST+FT thiamethoxam and ST thiamethoxam were found to be on par with 2FT quinalphos.

Pooled analysis of the two season data revealed that 2 FT thiamethoxam and 2 FT imidacloprid were significantly superior in producing the highest number of flowers (4.66) as compared to the untreated control (2.00) followed by ST thiamethoxam and ST imidacloprid (3.33). No significant difference in flower production was noticed among the seed treatments, ST+FTand FT quinalphos. ST increased flower production by 66.5 per cent while ST + FT brought about 25 to 41.5 per cent increases in flowers in okra.

4.3.5. Impact of thiamethoxam and imidacloprid on fruit of okra

Influence of thiamethoxam and imidacloprid on number of fruits produced per plant are presented in Table 18.

In the season 1, FT thiamethoxam yielded the highest number of fruits per plant (26.70) showing significant superiority to all other treatments and untreated control (13.9). This was on par with ST thiamethoxam (24.13) and combination ST+FT imidacloprid (22.40). All insecticides increased the fruit yield.

In the season two also, all the insecticide treatments produced significantly higher yield than the untreated control. 2FT thiamethoxam was found to be significantly superior over all other treatments with the highest yield of 19.50 fruits per plant as against 7.8 fruits in untreated control.

Pooled data analysis of two seasons revealed that 2 FT thiamethoxam significantly increased the number of fruits in okra with 23.1 fruits/plant as against 10.85 fruits in untreated control. This treatment was found to be superior over all other treatments ST thiamethoxam showed 18.1 fruits while ST imidacloprid exhibits 14.45 fruits per plant. ST + FT treatments resulted in 16.05 and 17.85 fruits per plant.

4.3.6. Influence of thiamethoxam and imidacloprid on weight of fruit per plant

Season 1

Results on the effect of thiamethoxam and imidacloprid on fruit weight per plant are presented in Table 18. All insecticide treatments except ST imidacloprid significantly increased fruit weight as compared to untreated control. ST thiamethoxam recorded the highest weight of 246 g. However, it was on par with 2FT imidacloprid (216), ST thiamethoxam (232.3) and ST+FT thiamethoxam and ST + FT imidacloprid. Fruit weight in two FT quinalphos also showed no significant difference with other insecticide treatments. Fruit weight was found to be lowest in ST imidacloprid (163.3).

Table 17. Influence of thiamethoxam and imidacloprid on reproductive characters of okra

Treatments	Days for flower initiation				No.of flowers per plant			
	S 1	S 2	Pooled mean	% decrease over UC	S 1	S 2	Pooled Mean	% increase over UC
T_1- ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	34.33^{b} (5.90)	34.66^{de} (5.93)	34.50^{d} (5.92)	15.15	4.00^{abc} (2.11)	2.66^{b} (1.77)	3.33^{b} (1.94)	66.50
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	35.00^{b} (5.96)	34.33^{e} (5.902)	34.66^{d} (5.930)	14.75	3.33^{cd} (1.95)	3.33^{ab} (1.95)	3.33^{b} (1.95)	66.50
T_3 - 2 FT Thiamethoxam 25WDG @ 25g a.i. kg^{-1}	39.66^{a} (6.34)	40.333^{a} (6.389)	40.00^{ab} (6.36)	1.64	4.66^{ab} (2.27)	4.33^{a} (2.19)	4.5^{a} (2.23)	125.00
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	38.66^{a} (6.26)	39.33^{ab} (6.311)	38.99^{b} (6.28)	4.11	5.00^{a} (2.345)	4.33^{a} (2.19)	4.66^{a} (2.27)	133.00
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam25WG @ 25 g a.i. ha^{-1}	35.33^{b} (5.98)	36.66^{cd} (6.09)	36.00^{cd} (6.04)	11.47	2.33^{d} (1.68)	2.66^{b} (1.77)	2.49^{bc} (1.73)	24.50
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1}+ Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	35.33^{b} (5.98)	37.333^{bc} (6.15)	36.33^{c} (6.07)	10.66	3.33^{bcd} (1.95)	2.33^{bc} (1.67)	2.83^{b} (1.82)	41.50
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	39.33^{a} (6.31)	40.00^{a} (6.36)	39.66^{ab} (6.34)	2.45	2.33^{d} (1.67)	2.66^{b} (1.77)	2.50^{bc} (1.73)	25.00
T_8- Untreated Control	40.66^{a} (6.42)	40.66^{a} (6.42)	40.66^{a} (6.42)		2.33^{d} (1.67)	1.66^{c} (1.46)	2.00^{c} (1.57)	
CD Value	0.19	0.17	0.12		0.29	0.27	0.20	

S1 - Season 1, S2 - Season 2, ST- Seed Treatment, FT- Foliar Treatment, UC - Untreated control

Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT (P= 0.05)

4.3.7. Influence of thiamethoxam and imidacloprid on fruit length

Data on the influence of thiamethoxam and imidacloprid on the length of fruit during the first season (Table 18) indicated a significant increase of fruit length in FT thiamethoxam (15.88) and combination ST+FT imidacloprid (16.08) and they were on par with each other. All other treatments were significantly inferior and on par with each other even with untreated control.

In season 2 (Table 18), FT thiamethoxam and ST + FT imidacloprid recorded maximum fruit length (15.57cm) as comparaed to control (13.73). All other treatments were on par. But quinalphos showed no significant difference of fruit length with control.

Pooled analysis of the two season data revealed that (Table 18) foliar application of thiamethoxam and combination ST + FT imidacloprid significantly increased fruit length (15.72). Seed treatment with thiamethoxam, imidacloprid and ST + FT imidacloprid were next best treatments that increased the fruit length and they were on par. Quinalphos exhibited no significant effect on fruit length as it was on par with untreated control. Both thiamethoxam and imidacloprid, irrespective of their methods of application, exhibited a significantly increased length of fruits in okra.

Table 18. Effect of thiamethoxam and imidacloprid on fruit characters of okra

Treatments	Number of fruits/plant				Weight of fruit/plant (g)				Length of fruit (cm)			
	S 1	S 2	Pooled mean	% increase over UC	S 1	S 2	Pooled mean	% increase over UC	S 1	S 2	Pooled mean	% increase over UC
T_1- ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	24.13^{ab}	12.10^{b}	18.11^{d} (5.92)	66.91	232.30^{a}	116.30^{b}	174.30^{a} (14.78)	60.16	14.16^{b}	15.23^{ab}	14.69^{b} (3.90)	5.76
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg^{-1}	16.20^{cd}	12.70^{b}	14.45^{d} (5.93)	33.17	163.00^{b}	121.70^{b}	142.35^{b} (13.21)	30.80	14.66^{b}	14.86^{ab}	14.76^{b} (3.91)	6.26
T_3 - 2 FT Thiamethoxam 25WDG @ 25g a.i. kg^{-1}	26.70^{a}	19.50^{a}	23.1^{ab} (6.36)	112.90	246.00^{a}	191.70^{a}	218.85^{bc} (12.35)	101.09	15.88^{a}	15.57^{a}	15.72^{a} (4.03)	13.17
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	21.10^{bc}	14.23^{b}	17.66^{b} (6.28)	62.76	216.00^{a}	140.00^{b}	178.00^{bc} (12.67)	63.56	14.35^{b}	14.24^{bc}	14.29^{c} (3.85)	2.87
T_5- ST+F Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam 25WDG @ 25g a.i. ha^{-1}	19.70^{bc}	12.40^{b}	16.05^{cd} (6.04)	47.93	194.00^{ab}	115.00^{b}	154.5^{c} (11.90)	41.96	14.43^{b}	14.84^{ab}	14.63^{b} (3.89)	5.33
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg^{-1} + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	22.40^{ab}	13.30^{b}	17.85^{c} (6.07)	64.52	195.00^{ab}	128.70^{b}	161.50^{b} (13.29)	48.39	16.08^{a}	15.57^{a}	15.82^{a} (4.04)	13.89
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	24.10^{ab}	13.73^{b}	18.91^{ab} (6.34)	74.28	230.70^{a}	130.00^{b}	180.35^{d} (10.22)	65.73	14.23^{b}	13.75^{c}	13.99^{d} (3.81)	0.72
T_8- Untreated Control	13.90^{d}	7.80^{c}	10.85^{a} (6.42)		151.0^{b}	66.67^{c}	108.83^{e} (3.910)		14.05^{b}	13.73^{c}	13.89^{d} (3.79)	
CD Value (5%)	4.87	2.35	0.12		48.92	24.00	0.96		0.946	0.93	0.04	

S1 - Season 1, S 2 - Season 2, ST - Seed Treatment, FT - Foliar Treatment, UC - Untreated control

Figures in the parentheses are square root ($\sqrt{x}$+0.5) transformed values

In columns, means superscripted by a common letter are not significantly different by DMRT

4.4. Terminal residues of thiamethoxam and imidacloprid in okra

Result on the terminal residues in okra fruit samples, analysed at 15 days after second spraying, are furnished in Table 19. The residues were observed to be below detectable limit in all the treatments at 15 days after second spraying.

Table 19. Terminal residue of imidacloprid and thiamethoxam in okra fruits

Treatments	Residue at 15 Days after 2nd spraying (45DAS)
T_1. ST Thiamethoxam 30 FS @ 3 g a.i. kg^{-1}	† BDL
T_2 - ST Imidacloprid 48 FS @ 6g a.i. kg $^{-1}$	BDL
T_3 - 2 FT Thiamethoxam- 25WG @ 25 g a.i. kg^{-1}	BDL
T_4- 2FT Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	BDL
T_5- ST+FT Thiamethoxam 30 FS @ 3g a.i. kg^{-1} + Thiamethoxam25WG @ 25 g a.i. ha^{-1}	BDL
T_6- ST+FT Imidacloprid 48 FS @ 6g a.i. kg $^{-1}$ + Imidacloprid 70 WDG @ 25g a.i. ha^{-1}	BDL
T_7- 2FT Quinalphos 25 EC @ 250 g a.i. ha^{-1} (Standard check)	BDL
T_8- Untreated Control	-

ST - Seed treatment FT - Foliar treatment DAS - Days after sowing

† BDL - Below Detectable Limit

Detectable Level - 0.05 ppm

DISCUSSION

5. DISCUSSION

Two neonicotinoid insecticides thiamethoxam and imdacloprid applied as seed treatments, two foliar sprayings (15 and 30 DAS) and a combination of seed treatment followed by foliar spraying (30 DAS) were assessed for their biological activity against the major pests and natural enemies on okra under field conditions during two seasons in 2013-14. Neonicotinoid effect on plant growth parameters and the resultant terminal residues in okra fruits were also explored. The results of these studies are discussed hereunder to elucidate the findings.

5.1. Bioefficacy of thiamethoxam and imidacloprid on sucking pests of okra

The insecticidal activity of imidacloprid and thiamethoxam applied as seed dressing (ST), two foliar sprayings (2 FT) at 15 and 30 DAS and a combination (ST+FT) of seed treatment followed by foliar spraying at 30DAS against *Amrasca biguttula biguttula*, *Aphis gossypii* and *Bemisai tabaci* on okra were evaluated under field conditions in two seasons.

5.1.1. Seed treatment and foliar spraying of thiamethoxam and imidacloprid on *Amrasca biguttula biguttula*

Results of the pooled analysis of two seasons (Table 4) revealed a significantly superior effictiveness of thiamethoxam and imidacloprid in reducing the population of *A. biguttula biguttula* over the standard check quinalphos and untreated control (Fig.1). Upto 30 DAS, all three methods of application were significantly superior and were on par. No significant difference was observed between ST thiamethoxam @ 3 g a.i. kg^{-1} and ST imidacloprid @ 6 g a.i. kg in lowering the population as they showed 47.5 to 50.6 per cent reduction. The present finding is in conformity with Kohle *et al.* (2009) who observed that thiamethoxam and imidacloprid were significantly superior in controlling leafhopper in cotton. Sajjan and Praveen (2008) reported that ST imidacloprid was on par with ST thiamethoxam against the sucking pest population in cotton.

Thiamethoxam by all the three methods of application ST, FT and ST + FT recorded a lower leafhopper population than imidacloprid. Thiamethoxam was thus proved to be highly effective against *A. biguttula biguttula* indicating a population reduction of 50.64 per cent in

ST, 78 per cent in FT and 74 per cent in ST + FT (Fig.2). Foliar treatment with thiamethoxam (2FT) 25 g a.i. ha^{-1} at 15 and 30 DAS caused highest reduction (78 %) of leafhopper population followed by ST +FT at 30 DAS and was found equally effective as 2 FT (74 %) in reducing the population.

It can thus be concluded that upto 30-35 DAS, ST either with thiamethoxam 3g a.i. kg^{-1} or imidacloprid 6 g a.i kg^{-1} can be recommended against *A. biguttula biguttula.* Alternatively thiamethoxam seed treatment at 3 g a.i.ha^{-1} followed by a single foliar spraying with thiamethoxam at 25 g a. i. ha $^{-1}$ at 30 DAS could reduce leafhopper population effectively or two foliar sprayings (15 & 30 DAS) of thiamethoxam at 25 g a. i. ha $^{-1}$ and 2FT thiamethoxam was found more effective than quinalphos upto 50DAS.

The above findings of the present study corroborate with Misra (2000), who reported that thiamethoxam at 25 g a.i. ha^{-1} was significantly superior in controlling jassids in okra. Acharya *et al.* (2002) also recorded that thiamethoxam (25 g a.i. /ha) was effective in controlling okra jassids by recording 77.2 - 86.0 per cent reduction of jassid population.

5.1.2. Impact of thiamethoxam and imidacloprid on *Aphis gossypii*

Pooled analysis of two seasons data on *A.gossypii* (Table 7) proved the significantly superior toxicity of thiamethoxam and imidacloprid applied as ST, 2 FT, and ST+FT over the standard check 2 FT quinalphos against *A. gossypii* upto 45 DAS. They revealed a reduction in the aphid population from 60.2 per cent in ST thiamethoxam to 88.49 per cent in 2FT thiamethoxam (Fig. 3). Seed treatment with thiamethoxam 3 g a.i. kg^{-1} and imidacloprid 6 g a.i. kg^{-1} were equally effective in reducing (60.20%) the aphid population. The present findings are in conformity with Vadodaria *et al.* (2001) who reported that seed dressing with insecticides *viz.,* thiamethoxam (cruiser) 70 WS at 4.3 and 2.8 g kg^{-1} seeds, imidacloprid (Gaucho) 700 FS at 12 ml and 9 ml kg^{-1} seeds and imidacloprid 70 WS at 7.5 g kg^{-1} seeds kept the population of aphids in cotton below ETL level and untreated control. Kohle *et al.* (2009) observed that imidacloprid seed treatment (10g kg^{-1} seed), and both concentrations of thiamethoxam (0.005 and 0.01 %) were most and equally effective against aphid.

Foliar spraying (FT) with both the neonicotinoids, thiamethoxam 25 g a.i. ha^{-1} and imidacloprid 25 g a.i. ha^{-1} exhibited significantly superior reduction of 88 per cent in the aphid population as compared to 62 per cent in the standard check quinalphos (Fig.3). Both the treatments were equally effective. Our findings are in line with the reports of Misra (2002), who observed that imidacloprid and thiamethoxam @ 25 g a.i. ha^{-1} were significantly superior in controlling aphids on okra compared to other conventional insecticides. Similar findings were also revealed by El-Naggar *et al.* (2013), who proved imidacloprid (Best 25% W.P.) and thiamethoxam (Actara 25% W.P.) as foliar applications were highly effective against aphids in cotton. Similarly El-Zahi and Aref (2011) found that thiamethoxam and imidacloprid were most effective against cotton aphids under field conditions.

The highest population reduction in foliar treatment with either thiamethoxam or imidacloprid was closely followed by ST+ FT of thiamethoxam and imidacloprid showing 81 to 83 per cent reduction. The standard check insecticide quinalphos 2FT at 250 g a.i. ha^{-1} revealed lesser effectiveness as compared to FT neonicotinoids.

ST thiamethoxam 3 g a.i.kg^{-1} and ST imidacloprid 6 g a.i.kg^{-1} was on par with quinalphos 2FT at 250 g a.i. ha^{-1}. However, upto 30 DAS, ST thiamethoxam and ST imidacloprid were significantly effective than FT quinalphos indicating that ST can be recommended in the early growing period upto 30 days followed by a FT against aphids so that insecticide load in the environment can be reduced.

All the three application methods (seed treatment, foliar treatment and combination treatment of seed treatment followed by foliar treatment) of thiamethoxam and imidacloprid were equally effective against *A.gossypii* upto 25 DAS.

5.1.3. Toxicity of thiamethoxam and imidacloprid on *Bemisia tabaci*

Findings of the two seasons indicated that in both seasons thiamethoxam and imidacloprid showed lower number of white flies as compared to the untreated control. In both the seasons, among the different treatments 2FT imidacloprid exhibited better efficiency with the lowest mean whitefly population (Fig. 4). It was followed by ST+FT imidacloprid in Season 1 and the standard check quinalphos 2FT (season 2) showed more effectiveness against white flies.

Fig. 1. Influence of thiamethoxam and imidacloprid on leafhopper population in okra

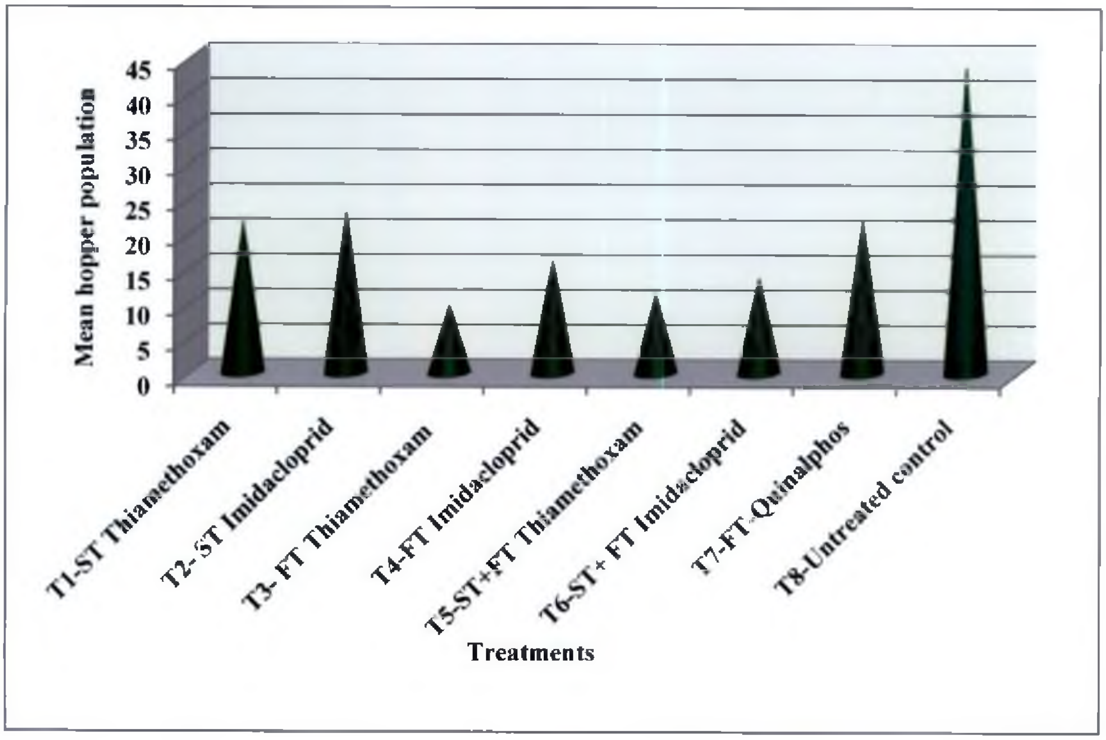
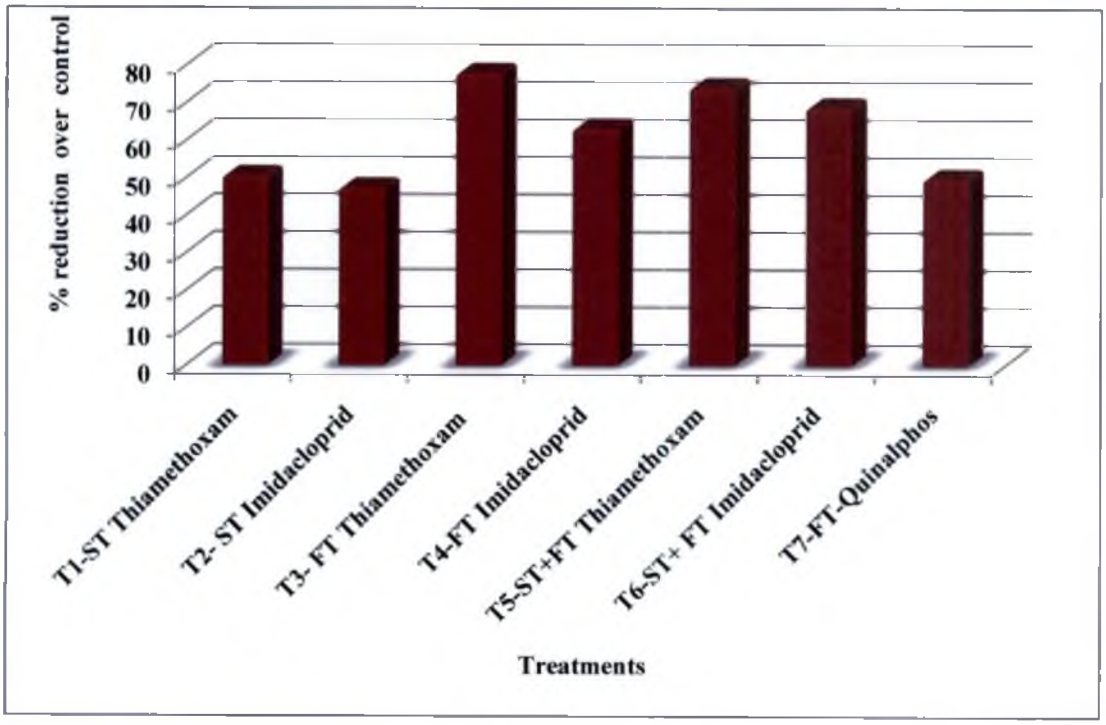


Fig. 2. Effect of thiamethoxam and imidacloprid on population reduction of leafhopper



Horowitz *et al.,* (1998), reported that imidacloprid at 25 g a.i. ha^{-1} effectively controlled the whitefly, *B. tabaci* in cotton. According to Ghoshal and Chatterjee (2013) imidacloprid 17.8 SL @ 50 g a.i. ha^{-1}, was found superior against whiteflies. Bhargava and Bhatnagar (2001) reported that two formulations of imidacloprid 600 FS at the rate of 9 ml kg^{-1} and 70 WS at the rate of 10 g kg^{-1} okra seed treatment performed well against whiteflies at Jaipur (Rajasthan) in okra. Dey *et al.* (2005) found that all the dosages of imidacloprid 70 WS *viz.,* 5, 7.5 and 10 g kg^{-1} seed provided excellent protection against whiteflies upto 45 days after sowing in okra. In the present study, the treatments did not show any significance which might be due to the very low incidence of whitefly population in the experimental field.

Combination of ST thiamethoxam 3 g a.i. kg^{-1} seed followed by FT thiamethoxam 25 g a.i. ha^{-1} seed and combination of ST imidacloprid 6 g a.i. kg^{-1} seed followed by FT imidacloprid showed the population of 0.15 and 0.05. Showing the efficacy of imidacloprid over thiamethoxam combination treatment.

In all the application methods *viz.,* ST imidacloprid 6 g a.i. kg^{-1}, FT imidacloprid 25 g a.i. kg^{-1} and combination of ST + FT imidacloprid was found to better than thiamethoxam against whit flies. Our findings are in line with findings of Mote *et al.* (1994), who reported that imidacloprid, the new systemic chloronicotinyl group of insecticide, was effective against whiteflies *Bemisia tabaci.*

In the second season, the whitefly population was lower in ST imidacloprid at 6 g a.i. kg^{-1} seed than ST thiamethoxam.

In the foliar treatments FT imidacloprid 25 g a. i.ha^{-1} recorded least population (0.39) over FT thiamethoxam 25 g a. i. ha^{-1}. In imidacloprid foliar treated plants, the compound and its metabolites are initially toxic to feeding adults, but also repel adults and act as anti-feedants consequently; establishment by immature whiteflies on plants is significantly reduced because of suppressed egg deposition (Nauen and Elbert, 1997; Nauen *et al.,* 1998).

In the seed treatment and foliar application treatment, imidacloprid recorded least population. In both the seasons, imidacloprid FT 25 g a. i. ha^{-1} was found to be superior over control. Our findings are in disagreement with the findings of Naveen *et al.* (2011) who

Fig. 3. Impact of thiamethoxam and imidacloprid on population reduction of *Aphis gossypii*

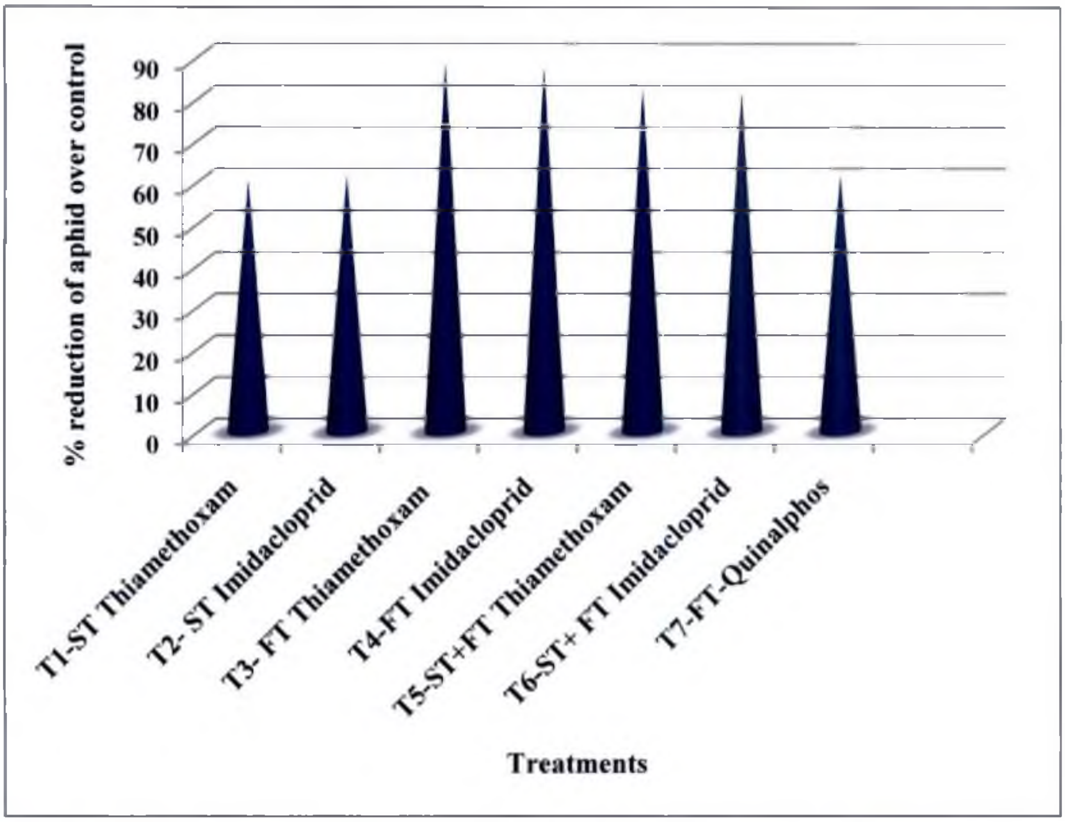
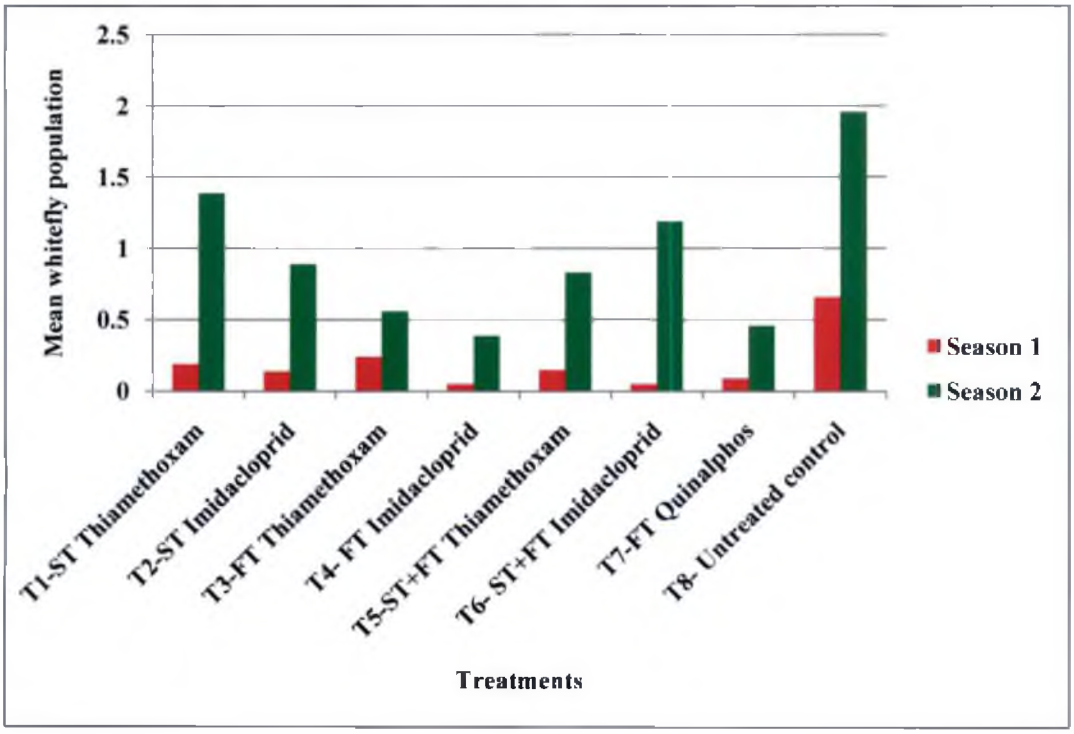


Fig.4. Efficacy of thiamethoxam and imidacloprid on whitefly population in okra



found that imidacloprid was effective for controlling *B. tabaci* at Prathipadu (Andhra Pradesh).

5.2. Seed treatment and foliar spraying of thiamethoxam and imidacloprid against chewing pests of okra

5.2.1. Impact of thiamethoxam and imidacoprid on *Sylepta derogata*

Results (Table 10) on the effect of thiamethoxam and imidacloprid, applied as seed treatment, foliar treatement as well as a combination of both, against *Sylepta derogata* indicated that the leaf roller damage was very low in both the seasons. Hence only mean percent damage per plant was worked out.

In the first season, all treatments showed a lesser leaf damage by *S.derogata* than the untreated control. The mean per cent damage per plant varied from 0.66 in 2 FT imidacloprid to 1.99 in ST thiamethoxam as against 2.39 per cent in untreated control (Fig.5). Combination of ST+FT thiamethoxam and imidacloprid recorded 1.59 per cent and 1.73 per cent damage in leaves of okra.

The second season also indicated the same trend of lower leaf damage in all the treatments than the untreated control. Two FT imidacloprid and ST thiamethoxam recorded no incidence of damage by *S. derogata*. But ST+FT imidacloprid showed higher damage (2.04 %) as compared to other treatements. From the above findings it was observed that among the tested treatments, two foliar sprayings with imidacloprid @ 25 g a.i. /ha at 15 and 30 DAS was more effective for protecting the crop from leaf roller damage. The present finding corroborates with the earlier reports wherein the efficacy of imidacloprid against the lepidopteran pest *Helicoverpa armigera* Hubner was revealed in tomato (Hussain and Bilal, 2007; Ulaganathan and Gupta, 2004 and Lavekar *et al.*,2004). It was also reported that 40 per cent chlorantraniliprole. thiamethoxam WG were highly efficient in providing longer effective protection against rice leaf-roller (*Cnaphalocrocis medinalis*) in early rice, medium rice and late rice (Tao *et al.*, 2010).

5.2.2. Impact of thiamethoxam and imidacloprid on shoot borer *Earias vitella*

In the first season there was no damage incidence by shoot borer upto 35 DAS (Table 11). Significant differences between treatments were observed only at 40 DAS. Foliar sprayings (2 FT) with thiamethoxam @ 25 g a.i. ha^{-1} at 15 and 30 DAS significantly reduced the shoot damage by *E.vitella* and was on par with 2FT imidacloprid indicating that both were equally effective in reducing the shoot borer damage. All the other treatments, including the standard check quinalphos were on par with the untreated control revealing their non-significant effect on shoot borer. Parmar *et al.* (2013) observed less effectiveness with foliar spraying of imidacloprid @0.0053 % against shoot and fruit borer infesting okra.

Incidence of shoot borer damage was very low in the 2nd season also and so no statistical analysis was done. Two FT thiamethoxam continued to be the best treatment against shoot borer damage. ST +FT thiamethoxam also showed no incidence of shoot borer damage.

From the both seasons data it may be concluded that 2 FT thiamethoxam @ 25 g a.i. ha^{-1} effective in controlling the shoot damage by *E. vitella.* This is in conformity with the findings of Karmakar and Kulshrestha (2009) who reported that thiamethoxam at normal and double the recommended use rate effectively controlled the borer *Helicoverpa* sp. in tomato.

5.2.3. Impact of thiamethoxam and imidacoprid on fruit borer *Earias vitella*

Pooled analysis of the two seasons data (Table 12, Fig.6) revealed that thiamethoxam and imidacloprid by the three methods of application (ST, 2 FT and ST+ FT) reduced 34.88 per cent to 78.04 per cent damage in fruits by *E.vitella.* The present finding is in line with Hussain and Bilal (2007), Ulaganathan and Gupta (2004) and Lavekar *et al.* (2004) who reported that imidacloprid treatments were more effective against the fruit borer damage by *Helicoverpa armigera* Hubner in tomato. Imidacloprid due to their quick knock down effect, low mammalian toxicity and longer persistence on the treated surface can safely be used in controlling the fruit borer infesting tomato (Mishra, 1986; Singh and Singh 1990; Bhatt and Patel, 2002). The combination of imidacloprid 200 SL @ 0.25 ml l^{-1} + propiconazole 25 EC @ 1.0 ml l^{-1} was found most effective against both stem borer and leaf blast in rice (Prasad *et al.*, 2009).

The extent of damage reduction in terms of both number and weight of fruits was found to be more or less equal in all the treatments in the present study. Two FT thiamethoxam at 25 g a.i. ha^{-1} was proved to be significantly the best treatment as revealed by the maximum reduction in fruit damage on number (78.04 per cent) and weight (78.29%)

basis. Karmakar and Kulshrestha (2009) reported the efficacy of thiamethoxam at normal and double the recommended use rate on *H. armigera* in tomato.

Two FT imidacloprid at 25 g a.i. ha^{-1} was the second best treatment with 67-69 per cent reduction of fruit damage by *E.vitella*. Combination treatment (ST+FT) of imidacloprid and thiamethoxam reduced the damage by 60 and 47 per cent in fruit number and weight. Seed treatment with thiamethoxam reduced 53 per cent fruit damage where as the seed treatment with imidacloprid was least effective in reducing fruit damage with only 34.88 per cent reduction of damage in fruits.

5. 3. Safety of thiamethoxam and imidacloprid to predators in okra ecosystem

5. 3. 1. Coccinellids

In both seasons, coccinellid population was found to be less in all insecticide treatments as compared to the untreated control (Table 13). Coccinellid population was higher during the second season than the first season which might be due to the difference in the weather conditions prevailed in that period.

Among the different treatments, imidacloprid by all the three application methods of ST+FT, FT and ST recorded lower coccinellid population than thiamethoxam indicating that thiamethoxam was safer than imidacloprid. Two FT recorded the maximum population during first season while in second season ST revealed the highest population of coccinellids.

From this it could be concluded that all the treatment of imidacloprid as seed treatment at 6 g a.i. kg^{-1}, as foliar treatment at 25 g a.i. ha^{-1} or the combination of seed treatment followed by foliar treatment with imidacloprid is deleterious to the coccinellid population. The present finding is in agreement with Khani, *et al.* (2012), who revealed that the toxicity of imidacloprid (technical grade with 95% purity) was approximately 3 times higher than that of abamectin for citrus mealybug predator *C. montrouzieri* reared on *Planococcus citri* infested squash and potato females based on LC50 values. Smith and Krischik (1999) indicated that imidacloprid might not be compatible with the coccinellid predator *Coliomegilla maculata* because there was a significant decrease in the general mobility of the predator in imidacloprid treated plants. It was observed that the contact action of imidacloprid caused toxic effect against coccinellid up to 20 days (Viggiani *et al.*, 1999). Patil and Lingappa (2000) reported from a laboratory study that imidacloprid at 0.07 per cent

Fig.5. Impact of thiamethoxam and imidacloprid on leaf roller damage

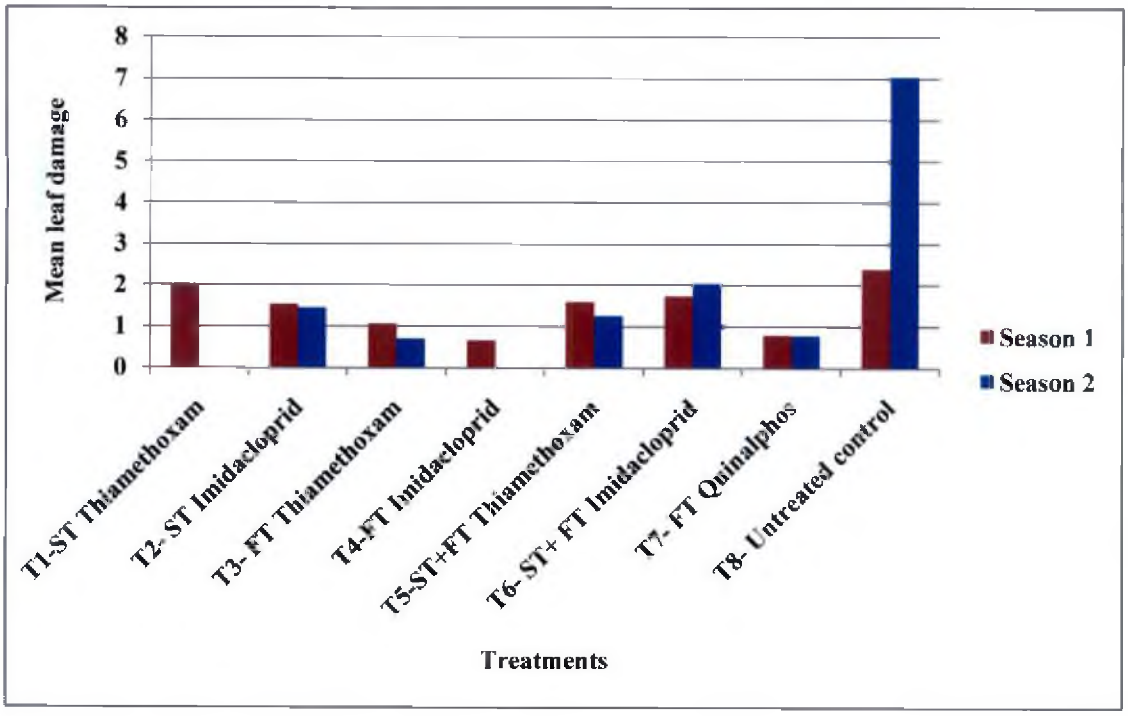
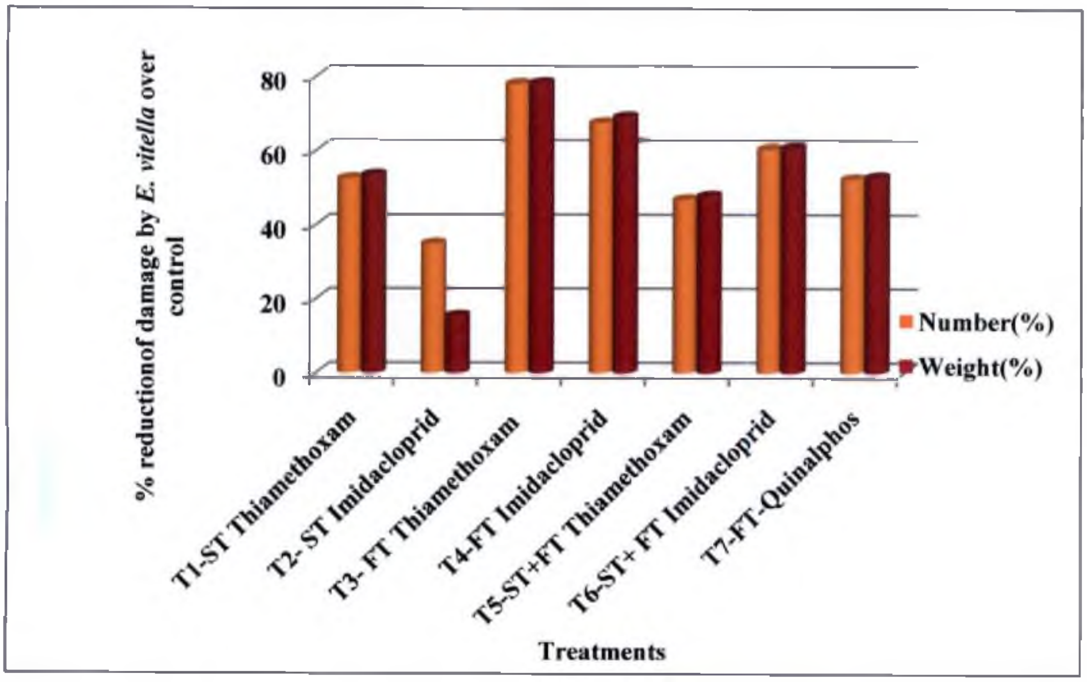


Fig.6. Efficacy of thiamethoxam and imidacloprid on damage reduction of fruit borer



was persistent up to 15 days and caused 24.7 per cent mortality of *Coccinella sexmaculata* adults.

Among the insecticide treatments in the present study, highest number of coccinellids was observed in 2FT thiamethoxam at 25 g a.i. ha^{-1} (1.77). This is in conformity with the findings of Tamilvel (2004), who reported that foliar application of thiamethoxam 25 WG (0.02%) was proved less toxic to coccinellid and spider populations in okra. Quinalphos 2 FT also recorded very low population (0.22).

In the second season, highest mean population per plant was recorded for untreated control (3.77), which was followed by ST thiamethoxam (2.66) (Fig. 7). This is not in agreement with the findings of Satpute *et al.* (2002), who reported that seed treatment with imidacloprid under higher doses was observed to be attractive to the coccinellid predators in cotton. In both the seasons, thiamethoxam was thus found to be safer than imidacloprid to coccinellids.

In both the seasons imidacloprid was safer than quinalphos with respect to coccinellid population. This finding is in conformity with the findings of James and Coyle(2001); Youn *et al.* (2003) who observed that imidacloprid was much less toxic to natural enemies than, organophosphate, carbamate, pyrethroid, ethofenprox and acetamiprid. It was reported that imidacloprid at 0.025 per cent and acetamiprid at 0.002 per cent were safer to the aphid predators like *Menochilus sexmaculata* and *Coccinella transversalis* than organophosphate insecticides like chlorpyrifos (0.05%), profenofos (0.05%) and triazophos (0.05%) on cowpea (Varghese, 2003).

5.3.2. Safety of thiamethoxam and imidacloprid to spiders

In season 1, among the treatments two FT thiamethoxam recorded the highest spider population as compared to untreated control (Table 14). This treatment was followed by ST imidacloprid @ 6 g a.i.kg^{-1} which recorded a higher spider population than ST thiamethoxam (Fig. 7). This is in agreement with the findings of Kannan *et al.* (2004) observed that seed treatment of transgenic cotton with imidacloprid 5 g kg^{-1} seed was not only safe but also attracted predators, *viz.* Lynx spider, *Oxyopes javanus* (Thorell); orb spider, *Argiope minuta* (Karsh); wolf spider, *Lycosa pseudoannulata* (Boesenberg and Strand); long jawed spider, *Tetragnatha javana* (Thorell); *Neoscona theisi* (Walcknear) and *Peucetia viridana* (Stoliczka) in transgenic cotton. Combination treatment of thiamethoxam and 2 FT imidacloprid showed same population (0.22). Lowest population was observed in ST+FT imidacloprid and 2 FT quinalphos (0.11).

Season 2 recorded a higher spider population in all the treatments which might be due to the variation in weather parameters prevailed during the seasons. Among the treatments, ST thiamethoxam recorded the lowest population and highest in 2FT imidacloprid and ST+FT thiamethoxam. All the treatments showed lower population than the untreated control indicating their less safety to predators.

5.3.3. Safety of thiamethoxam and imidacloprid to other predators

In the first season, the mean population of other predators *viz,* rove beetle, chrysoperla and syrphids was highest in ST +FT imidacloprid (Fig. 7as compared to the untreated control. ST thiamethoxam was on par with the untreated control thus indicating its safety to the predators. Seed treatment with thiamethoxam at 3 g a. i. kg^{-1} was safer than ST imidacloprid at 6 g a.i.kg^{-1} seed.

In the foliar treatment method, both FT thiamethoxam and FT imidacloprid recorded the same reduction in the population of predators. Mathirajan and Regupathy (2002) observed that thiamethoxam 25 WDG (0.2g l^{-1}) showed no adverse effect on the hatchability of *Chrysoperla carnea b*ut the adult emergence, adult longevity and fecundity of *C.carnea* were found to be lowest in the insecticide treatment.

In the second season, highest population was recorded in ST thiamethoxam which was higher than untreated control 1.33 (Fig. 8). Thus ST thiamethoxam was found safe to natural enemies as revealed in the two seasons. But in the foliar treatments, 2 FT thiamethoxam was less safe as the population was lesser in thiamethoxam than imidacloprid. However, ST+ FT thiamethoxam was safer than ST+ FT imidacloprid. It is thus inferred that ST imidacloprid and ST+FT imidacloprid were less safe to predators. However, 2FT imidacloprid was safer than thiamethoxam.

From the above findings it can be concluded that seed treatment with thiamethoxam showed highest population of other predators. Our findings are in agreement with the findings of Katole and Patil (2000), who reported that cotton seed treatment with thiamethoxam at 4 g kg^{-1} allowed maximum oviposition of *Chrysoperla* sp. and was at par with untreated control and Vadodaria *et al.* (2001), who reported seed dressing, with thiamethoxam (Cruiser) 70 WS at 4.3 and 2.8 g kg^{-1} seed, did not affect the natural enemy population in cotton.

5.4. Influence of thiametoxam and imidacloprid on plant growth

5.4.1. Height of the plant

Pooled analysis data of the two seasons revealed that (Table 16) FT thiamethoxam was significantly superior in increasing plant height (98.62cm) of okra indicating 46.96 per cent increase in height over control (Fig.9). Our findings are in line with those of Prasanna *et al.* (2004) who reported that there was a significant increase in plant height due to foliar spray (25 g a.i. ha^{-1}) on cotton. Praveen (2005) reported that foliar spraying with thiamethoxam (Actara 25 WS) at 0.40 g L^{-1} revealed an effect on the plant height at 55, 65 and 75 DAS in okra. Verma and Kanwar (2009) observed that the plant height (141.63 cm) was maximum in thiamethoxam seed treatment in okra. Seed treatment thiamethoxam and imidacloprid showed 27 to 31 per cent increase in plant height and they were on par. Mote (1993) observed an increase of plant height and leaves with imidacloprid (1to 5 per cent a.i. w/w) seed treatment of sorghum. In cotton, imidacloprid (Gaucho) seed treatments showed increased plant height over control (Graham *et al.,* 1995). The plant height, number of fruits per plant and yield were found to be superior in imidacloprid seed treated plants in okra (Mote *et al.*, 1994). The plant height was superior in plots with imidacloprid 600 FS and 70 WS than the untreated check in okra (Bhargava and Bhatnagar, 2001).

Thiamethoxam 2 FT @ 25 g a.i. ha^{-1} revealed 36.21% height increase of plant height over control and was on par with combination ST+FT imidacloprid. ST + FT thiamethoxam and imidacloprid brought about 34.5 and 36.2% increase in height of okra plants. But quinalphos showed the lowest (11.6%) increase in plant height.

5.4.2. Leaves per plant

Two season's data revealed that two FT thiamethoxam and ST+FT imidacloprid produced significantly higher number of leaves as compared to all other treatments (Table 16). These treatments revealed 48 – 49 per cent increase in the number of leaves. Such a

Fig.7. Impact of thiamethoxam and imidacloprid on natural enemies population (season 1)

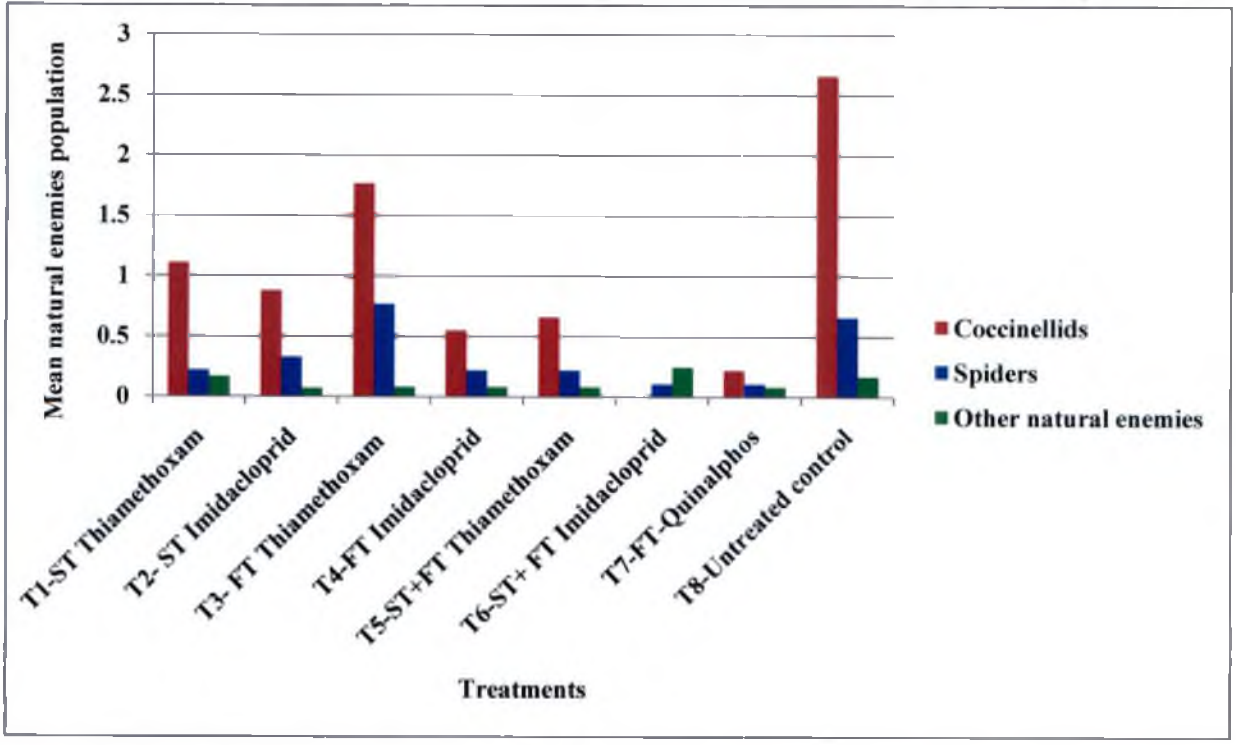
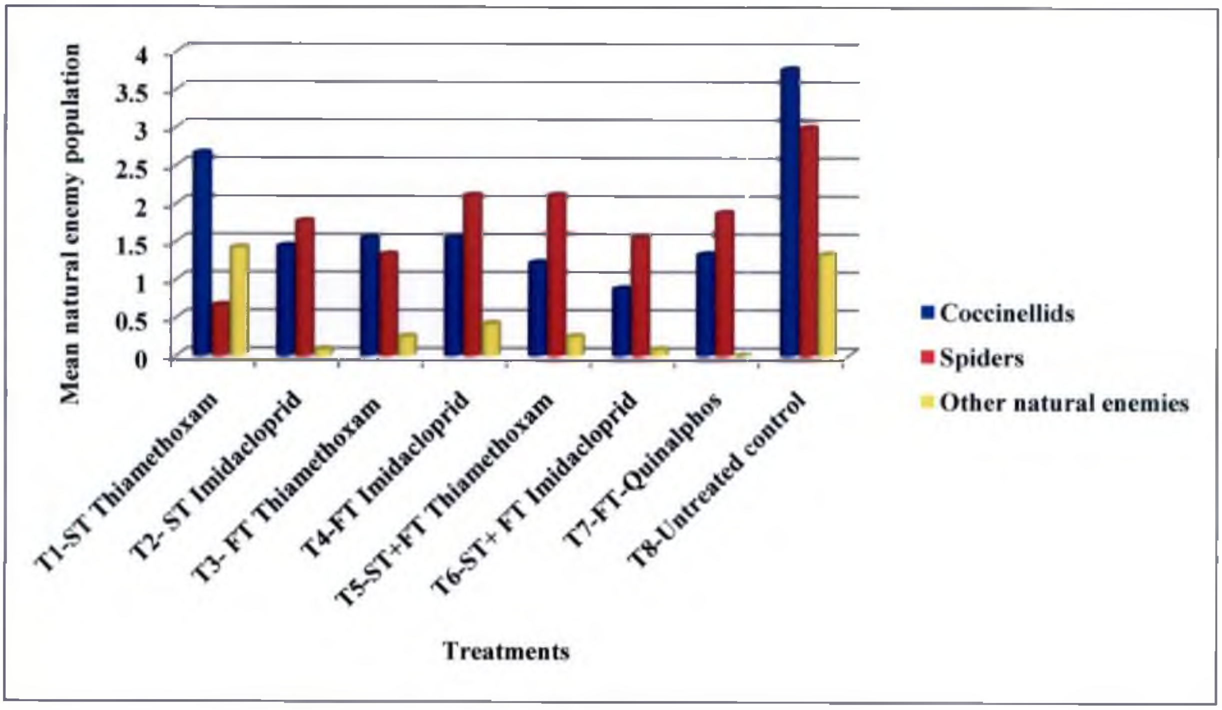


Fig.8. Impact of thiamethoxam and imidacloprid on natural enemies population (season 2)



significant increase in number of leaves due to thiamethoxam foliar spray (25 g ai ha^{-1}) was earlier reported in cotton by Prasanna *et al.* (2004).

Leaf production was more in thiamethoxam than imidacloprid by ST and 2FT (Fig.9). ST thiamethoxam indicated 32.31 per cent increase of leaf production while ST imidacloprid showed the lowest (11.55 %) increase over untreated control. Two FT imidacloprid increased the leaf production by 35 per cent. In sorghum, imidacloprid (1to 5 per cent a.i. w/w) seed treatment showed an increase of plant height and leaves (Mote, 1993).

Combination of seed treatment followed by foliar application with thiamethoxam and imidacloprid led to 20.76 and 49.09 per cent increase in the number of leaves per plant in okra. The conventional insecticide quinalphos 2FT also resulted in 15.88 per cent increase in leaf production.

5.4.3. Days to flower initiation

Number of days required for flower initiation in okra was significantly reduced by ST thiamethoxam (34.50 days) and ST imidacloprid (34.67 days) as compared to 40 days in untreated control (Table 17) thus indicating no difference between them. According to Dey *et al.* (2005), imidacloprid 70 WS @ 5-10 g per kg seed produced less number of days to flower initiation (38.1 days) over control (42.30 days). ST+FT thiamethoxam and imidacloprid indicated 10.7 to 11.5 per cent reduction in the number of days for flower initiation (Fig. 10). But foliar application of thiamethoxam 25 g a.i. ha^{-1} or imidacloprid caused no significant reduction in days for flower initiation and 2FT thiamethoxam was found to have no effect on flower initiation. This is in agreement with the findings of Praveen (2005), who reported that there is no difference on days to flower initiation in flower initiation in okra due to foliar spraying with thiamethoxam at 0.40 g $L^{-1.}$ Quinalphos also showed no significant effect on flower initiation.

5.4.4. Flowers per plant

Pooled analysis of the two seasons data (Table 17) revealed that 2 FT thiamethoxam and 2 FT imidacloprid were significantly superior in producing the highest number of flowers (4.66) per plant as compared to the untreated control (2.00) and both were on par. They were followed by seed treatments with thiamethoxam and imidacloprid. Comparatively less effect was exhibited by ST+FT combinations with 25 to 41.5 per cenet increase in flower production of okra (Fig.12). FT quinalphos indicated no significant effect on flower production.

5.4.5. Fruits per plant

A significant increase in the number of fruits (23.1 fruits) per plant in okra was observed with 2 FT thiamethoxam as against 10.85 fruits in untreated control (Table 18) thus indicating 112.90 per cent increase (Fig. 12). Our findings corroborate with the findings of Prasanna *et al.* (2004), who reported that there was a significant increase in fruiting bodies due to foliar spray (25 g ai ha^{-1}) on cotton. But the present findings are contrary with findings of Praveen (2005), who indicated that foliar application with thiamethoxam at 0.40 g L^{-1} recorded significantly less number of fruits (5.58) per plant. The number of fruits per plant and yield were superior in plots with imidacloprid 600 FS and 70 WS than the untreated check in okra (Bhargava and Bhatnagar, 2001). This is in agreement with our findings wherein ST imidacloprid 48FS resulted in 33.17 per cent increase in yield as compared to untreated control. ST + FT treatments recorded in 16.05 and 17.85 fruits per plant, showing 47.9 and 64.5 per cent increase in fruit production.

5.4.6. Weight of fruits per plant

Two FT thiamethoxam showed significant superiority in increasing the weight of fruits in okra. It showed an increase of 101 per cent over untreated control (Fig. 12). It was followed by two FT imidacloprid with 63.56 per cent increase in fruit weight. ST with imidacloprid and thiamethoxam brought about 31 to 60 per cent yield increase. Kumar (1998) reported that cotton yield was found to be increased with imidacloprid 70 WS at 7 g/kg seed. ST +FT increased fruit weight by 42 to 48 per cent, thus indicating the significant effect of insecticide treatments on fruit weight. The increase in yield might be attributed to the effective management of the insect pests during the vegetative and reproductive growth periods of the crop and also due to the phytotonic effects of the neonicotinoids.

5.4.7. Fruit length

Pooled analysis of two seasons data revealed that (Table 18) both thiamethoxam 2 FT and combination ST + FT imidacloprid significantly increased fruit length by 13 per cent and both were on par (Fig 12). Our findings are in agreement with Praveen (2005), who reported that foliar spraying with thiamethoxam (Actara 25 WS) at 0.40 g L^{-1} revealed an effect on the fruit length, which caused significantly higher fruit length of 14.28 cm. ST imidacloprid was

Fig.9: Influence of thiamethoxam and imidacloprid on plant height and leaves of okra

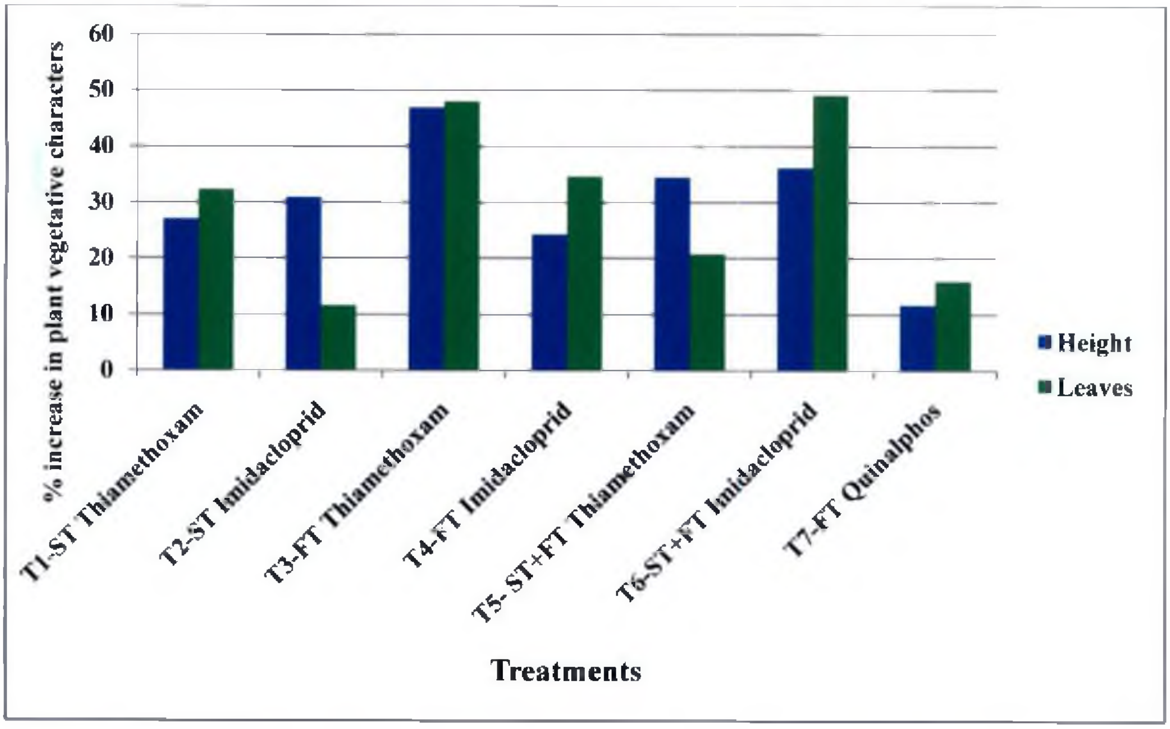
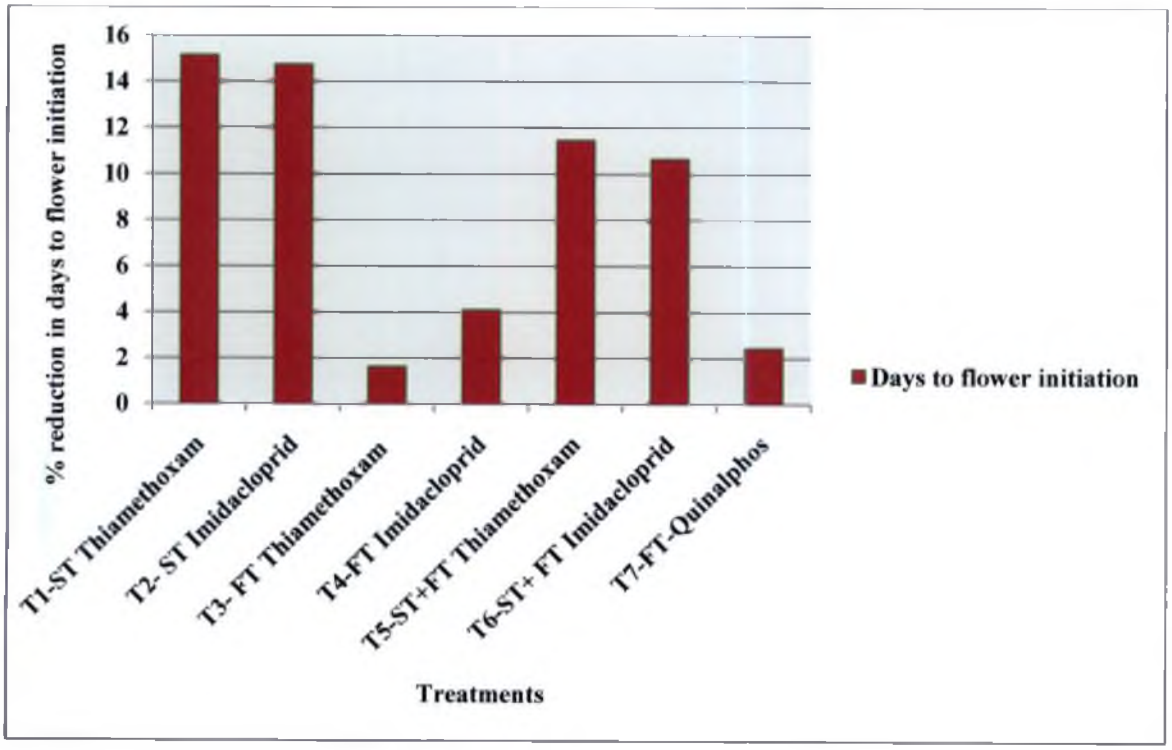


Fig.10. Impact of thiamethoxam and imidacloprid on days to flower initiation in okra



found to be next best treatment in increasing the fruit length (14.76 cm) as it showed 6.26 per cent increase in length. Dey *et al.* (2005) also observed a similar increase in fruit length (14.85 cm) with imidacloprid 70 WS @ 5-10 g per kg okra seed. Seed treatment with thiamethoxam, ST imidacloprid and ST+FT thiamethoxam were equal in their effect on increasing the fruit length. The standard check insecticide quinalphos 2FT exhibited no significant effect on fruit length as it was on par with untreated control.

5.5. Terminal residue of thiamethoxam and imidacloprid in okra

The residues of thiamethoxam and imidacloprid, at 15 days after second spraying, in okra fruit samples were observed to be below detectable limit of 0.05 ppm in all the treatments. Our findings corroborate with many earlier findings. Sharma and Soudhamini (2005) tested the persistence of thiamethoxam residues in okra following foliar application of thiamethoxam @ 0.2 and 0.4 g L^{-1} and found residues of the insecticide dissipated fast to be below detectable limits within 7-10 days after their last application. Santharam *et al.* (2003) determined the residues of imidacloprid in chilli fruits when applied at 250, 375 and 500 ml ha^{-1} and reported that the residue was below detectable limit and below the codex and EU MRLs, *i.e.*, 0.5 mg kg^{-1}. Hassan *et al.* (2005) applied imidacloprid @ 345 g a.i. ha^{-1} and found its residues as 0.038, 0.020 and 0.015 ppm after 3 hours, 3 days and 7days respectively, in the eggplant fruit by HPTLC considering the MRLs for eggplant fruit 0.2 to 1 ppm. Akbar *et al.* (2010) reported that conventional insecticides were found to be more persistent in the cabbage crop (average half life: 1.95, 2.42 and 1.57 days for imidacloprid, endosulfan and profenofos respectively) than bioinsecticides (average half life 1.25 and 0.27 days for spinosad and biosal). Residues of all tested insecticides were compared with codex and EU MRLs (MRL 0.5 mg kg^{-1}) and found that imidacloprid being biorational (low risk) was safe for consumption on the next day of application.

Fig.11.Impact of thiamethoxam and imidacloprid on reproductive characters of okra

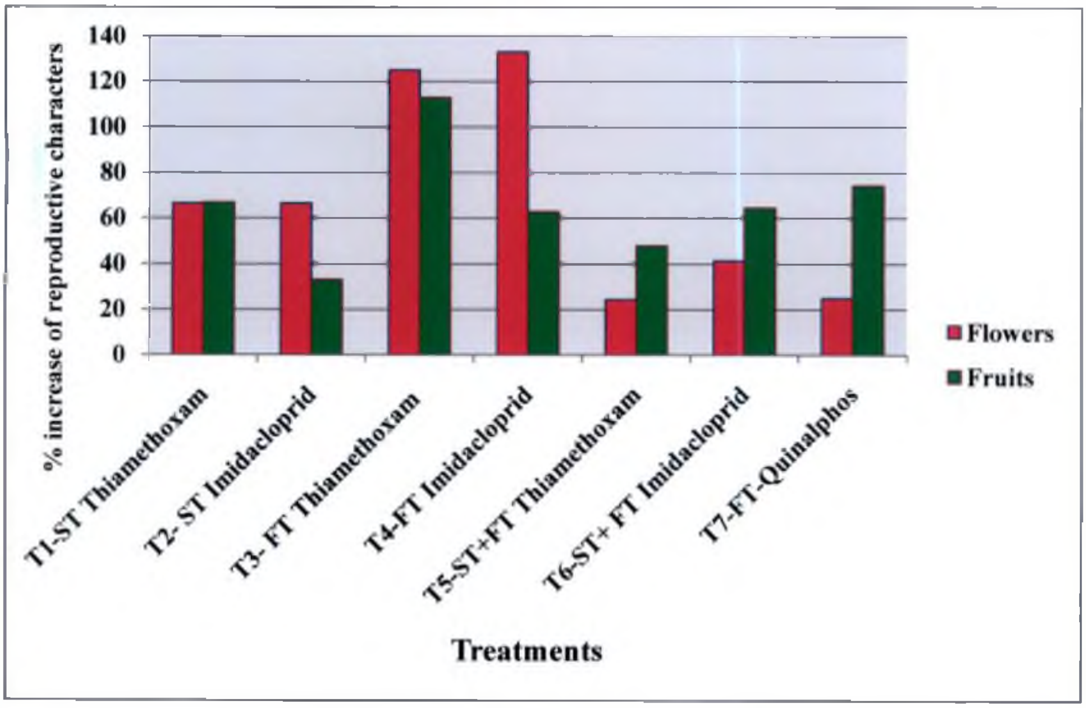
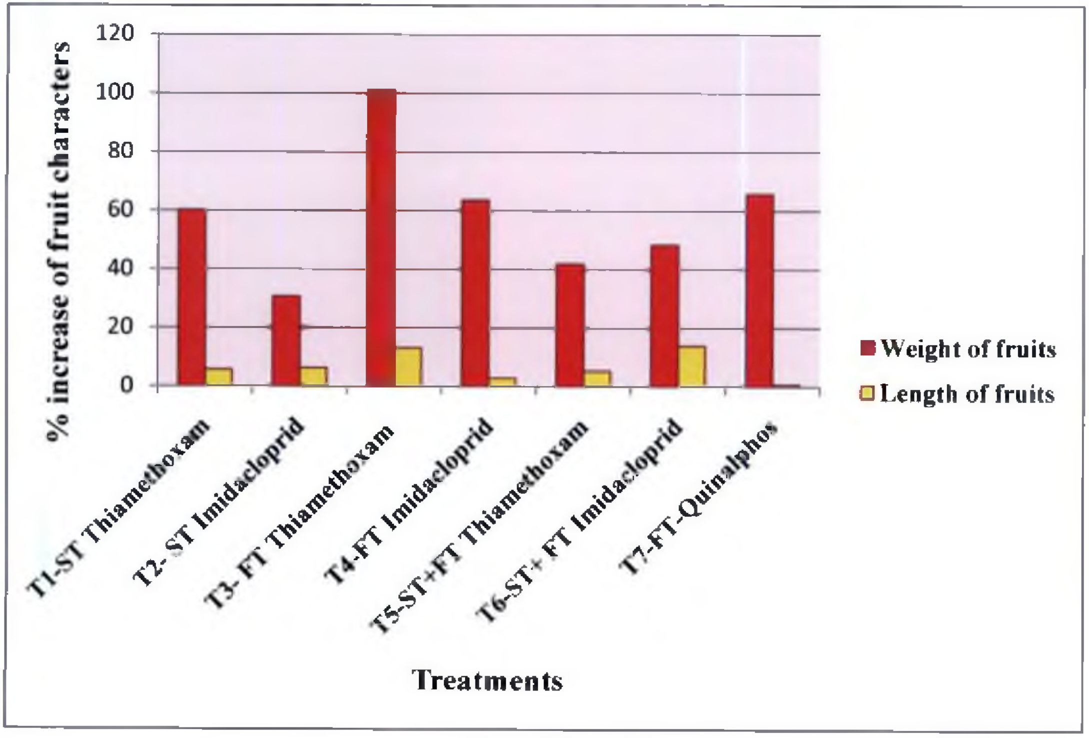


Fig.12. Influence of thiamethoxam and imidacloprid on fruit characters



SUMMARY

6. SUMMARY

The present study entitled "Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) Moench)" was undertaken in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara, Kerala Agricultural University during 2013- 2014. The study was carried out by conducting two field experiments at the Instructional Farm, College of Horticulture in two seasons viz., April 2013 to July 2013 and October 2013 to January 2014 under the prevailed weather conditions. Two neonicotinoid insecticides - thiamethoxam and imidacloprid - were evaluated for their biological efficiency against major insect pests of okra, safety of thiamethoxam and imidacloprid to the natural enemies, influence of thiamethoxam and imidacloprid on plant growth parameters of okra and to find out the persistence of thiamethoxam and imidacloprid residues in okra fruits. The insecticides were applied in three different methods *viz.*, seed treatment at sowing (ST), two foliar sprayings (2 FT) at 15 and 30 days after sowing and a combination of seed treatment followed by a single foliar spray (ST+FT) at 30 DAS on okra during two seasons in the field. Two foliar sprayings (2 FT) with quinalphos 25EC at 15 DAS and 30 DAS was also included as a standard check insecticide for comparison.

6.1. Bioefficacy of thiamethoxam and imidacloprid against major insect pests of okra

- **Leaf hopper, *Amrasca biguttula biguttula***

Both thiamethoxam and imidacloprid, irrespective of the methods of application, were significantly superior in efficacy as compared to the standard check quinalphos against leafhopper population. All the three methods of application of thiamethoxam and imidacloprid indicated equal effectiveness upto 30 DAS. Hence ST can be recommended upto 30 DAS. Thiamethoxam and imidacloprid seed treatments were equally effective against hoppers upto 30 DAS. ST+FT thiamethoxam proved to be equally effective to 2FT thiamethoxam throughout the season and hence it can be recommended against leafhoppers.

- **Aphid, *Aphis gossypii***

Thiamethoxam and imidacloprid by all the three application methods (seed treatment, foliar treatment and combination of seed treatment followed by foliar treatment) were equally effective against *A. gossypii* upto 25 DAS. From 30 to 50 DAS, 2FT thiamethoxam at 25 g a.i. ha^{-1} revealed a significant reduction of 88.49 per cent in the population of *A.gossypii.*

- **Whitefly, *Bemisia tabaci***

Two foliar sprayings with imidacloprid 70 WDG @ 25 g a.i. ha^{-1} at 15 and 30 DAS recorded the lowest population of whiteflies in okra. It was followed by ST imidacloprid. But 2 FT thiamethoxam exhibited less effectiveness on *B.tabaci.*

- **Leaf roller, *Sylepta derogata***

Over the two seasons 2 FT imidacloprid70 WDG @ 25 g a.i. ha^{-1} at 15 and 30 DAS proved to be superior over all other treatments in reducing the damage by *S.derogata* in okra.

- **Shoot borer, *Earias vitella***

In both seasons, two foliar sprayings (2 FT) with thiamethoxam 25WDG @ 25 g a.i. ha^{-1} at 15 and 30 DAS significantly reduced the damage by shoot borer *Earias vitella.* However, thiamethoxam by all the three methods of application – ST, ST+FT and FT - proved to be more effective than imidacloprid against the shoot damage by *E.vitella.*

- **Fruit borer, *Earias vitella***

Okra fruit damage by *E.vitella* was significantly reduced by two foliar sprayings with (2 FT) thiamethoxam 25WDG @ 25 g a.i. ha^{-1} at 15 and 30 DAS. It indicated the significant effectiveness in reducing the fruit damage, both in terms of fruit number and fruit weight. The two foliar sprayings with thiamethoxam revealed 78 per cent reduction in fruit damage. It was followed by 67.5 to 69 per cent damage reduction by 2FT imidacloprid 25 g a.i. ha^{-1}. But quinalphos, the recommended standard check, brought about only 52 per cent reduction of fruit damage.

6.2. Safety of thiamethoxam and imidacloprid towards natural enemies of okra pests

- **Coccinellids**

In the first season, among the insecticide treatments, highest number of coccinellids was observed in 2FT thiamethoxam at 25 g a.i. ha^{-1}. However, it recorded a lesser population as compared to the untreated control. In the second season also, highest mean population per plant was recorded for untreated control followed by ST thiamethoxam. Both thiamethoxam and imidacloprid by two foliar sprayings showed equal number of coccinellids.

- **Spiders**

The spider population was relatively less in all the treatments of thiamethoxam and imidaclopris as compared to the untreated control.

- **Other predators**

Thiamethoxam and imidacloprid showed no adverse effect on other predators such as syrphids, chrysoperla, rove beetles in ST with thiamethoxam. Their population was found to be on par / higher than the untreated control. All other treatments recorded a lower population than control.

6.2. Impact of thiamethoxam and imidacloprid on plant growth parameters of okra

All insecticide treatments significantly increased plant height and number of leaves in okra.

- **Height of the plant**

Two foliar applications of thiamethoxam 25 g a.i. ha^{-1} resulted in maximum increase of the height of okra plant by 46.96 per cent followed by combination ST+FT imidacloprid with 36.21 per cent increase in plant height. All treatments of thiamethoxam and imidacloprid significantly increased plant height indicating an increase ranging from 24.29 to 46.96 per cent as compared to untreated control.

- **Leaf production**

Two Foliar sprayings with thiamethoxam 25 g a. i. ha^{-1} given at 15 and 30 DAS and ST+FT imidacloprid produced highest number of leaves followed by 2FT imidacloprid in okra. Leaf production was increased by 49 per cent by ST+FT imidacloprid. Number of leaves was least in ST imidacloprid, FT quinalphos and combination ST+FT thiamethoxam.

- **Days to flower initiation**

Both thiamethoxam 3 g a.i. kg^{-1} and imidacloprid 6 g a.i. kg^{-1} by seed treatment significantly reduced the days required for flower initiation. They brought about a reduction of 15 per cent in the period for flower initiation thereby inducing earliness in flowering. ST+FT imidacloprid also significantly reduced the period for flower initiation in okra.

- **Number of flowers per plant**

All insecticide treatments significantly increased flower production in okra. Two foliar sprayings of both thiamethoxam and imidacloprid were equally efficient in revealing significant increase in the number of flowers per plant. Seed treatment with thiamethoxam and imidacloprid indicated 66 per cent increase in flower production as compared to the standard check quinalphos with only 25 per cent increase in flower production.

- **Number of fruits per plant**

Both neonicotinoid insecticide treatments significantly increased the fruit production in okra. Two foliar applications with thiamethoxam yielded the highest number of fruits (112% increases) whereas imidacloprid recorded 62.8 per cent increase. In ST also thiamethoxam 3 g a.i. kg^{-1} performed better (66.1% increase) than imidacloprid (33.17% increase). Two FT quinalphos revealed a higher increase of 74.28 per cent in fruit production.

- **Fruit weight per plant**

Thiamethoxam and imidacloprid by all the three methods of application exhibited a significant increase in the weight of fruits in okra. Fruit weight showed an increase from 30.80 per cent in ST imidacloprid to 101.1 per cent in 2FT thiamethoxam as compared to untreated

control. Seed treatment followed a foliar spraying indicated 42 to 48 per cent increase in the fruit weight.

- **Length of fruits**

Two foliar applications of thiamethoxam 25 g a.i. ha^{-1} and combination ST+FT imidacloprid significantly increased fruit length (15.72 - 15.82 cm) as against the untreated control (13.89) indicating 13 per cent increase of fruit length. Two foliar applications of imidacloprid showed only 2.87 per cent increase in fruit length. Seed treatments revealed 5.8 to 6.3 per cent increase in fruit length. Two sprayings with quinalphos showed no significant difference in fruit length.

6.4. Terminal residue in the fruit sample

Terminal residue in the fruit sample, analysed at 15 days after second spraying with thiamethoxam and imidacloprid at 30 DAS, revealed the residue to be below the detectable level of 0.05ppm in okra fruist.

It is thus concluded that seed treatment with either of thiamethoxam or imidacloprid can protect the crop from sucking pests upto 25-30 DAS. To protect the plant in the later stage foliar application is essential. Hence seed treatment along with foliar application of either thiamethoxam or imidacloprid can be applied, so that insecticide load in the environment can be reduced. Seed treatment with either thiamethoxam or imidacloprid was found to be very less effective against borer pests in okra. Both thiamethoxam and imidacloprid caused reduction in the population of natural enemies like coccinellids, spiders, syrphids, lacewing and rove beetle as compared with untreated control. Two foliar applications of thiamethoxam significantly increased the plant growth parameters like plant height, number of leaves, flowers per plant, fruit weight and fruit length. Seed treatment with either thiamethoxam or imidacloprid can induce early flower initiation in okra. Foliar application of thiamethoxam and imidacloprid at 30 DAS indicated the residue below detectable limit at 15 days after spraying when the produce is taken for consumption.

Appendix 1- Weather parameters during the cropping period

Month	Standard week number	Temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)	Rainy days	Evaporation (cm)
		Minimum	Maximum				
Season 1							
April – 2013	14	25.3	34.2	75	0.000	0	28.0
	15	25.7	35.4	73	0.000	0	33.4
	16	24.5	34.5	68	0.000	0	33.7
	17	25.1	35.2	69	0.000	0	32.1
	18	26.0	34.7	75	0.000	0	23.8
May -2013	19	25.8	34.3	75	0.000	0	26.1
	20	25.1	34.4	72	006.4	1	32.1
	21	24.6	34.0	77	005.7	1	17.2
	22	23.5	29.9	87	210.8	5	19.4
June – 2013	23	22.8	29.4	87	149.2	6	19.4
	24	22.3	28.6	92	302.5	7	19.4
	25	23.0	27.5	92	284.1	7	13.2
	26	22.9	28.6	89	172.2	6	12.9
July- 2013	27	22.8	28.6	91	247.5	7	16.2
	28	22.8	28.4	91	172.7	7	21.5
	29	22.7	27.5	93	276.8	7	17.5
	30	22.3	28.5	87	207.8	7	17.5
Season 2							
	31	22.8	28.9	89	185.8	6	17.1
October-2014	40	21.9	30.9	79	017.8	2	21.0
	41	22.6	30.7	83	060.1	3	20.3
	42	23.1	30.8	84	150.6	5	16.3
	43	23.0	29.6	87	117.1	5	15.6
	44	24.0	32.8	75	029.8	2	20.2
November-2013	45	24.1	32.4	65	0.000	0	28.3
	46	23.2	31.8	75	061.3	3	19.2
	47	23.9	32.9	79	013.2	1	18.3
	48	24.0	33.1	76	006.3	1	19.4
December-2013	49	22.4	32.3	63	000.5	0	25.1
	50	22.5	33.4	69	000.0	0	21.1
	51	21.8	31.4	60	000.0	0	34.5
	52	22.1	31.3	53	000.0	0	41.0
January-2014	1	22.4	32.6	54	000.0	0	36.1
	2	23.1	32.8	53	000.0	0	35.8
	3	23.7	33.2	50	000.0	0	37.6
	4	23.3	32.5	51	000.0	0	44.5
	5	22.3	33.7	47	000.0	0	43.3

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BIOEFFICACY OF NEONICOTINOID INSECTICIDES AGAINST INSECT PESTS OF OKRA (*Abelmoschus esculentus* (L.) MOENCH)

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ABSTRACT OF THE THESIS

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ABSTRACT

An investigation on "Bioefficacy of neonicotinoid insecticides against insect pests of okra (*Abelmoschus esculentus* (L.) Moench)" was undertaken in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara, Kerala Agricultural University during 2013- 2014. The study was carried out by conducting two field experiments at the Instructional Farm, College of Horticulture in two seasons *viz.*, April 2013 to July 2013 and October 2013 to January 2014.

Two neonicotinoid insecticides - thiamethoxam and imidacloprid - were field evaluated for their biological efficiency against major insect pests of okra, safety to natural enemies, influence on plant growth parameters and terminal residues in okra fruits. The two insecticides were applied in three methods *viz.*, seed treatment (ST), two foliar treatments (2 FT) and a combination of seed treatment followed by a single foliar treatment (ST+FT). The treatments comprised of ST thiamethoxam 30FS @ 3 g a.i. kg^{-1} (T1) and ST imidacloprid 48FS @ 6 g a.i. kg^{-1} (T2) before sowing, two foliar sprayings (2FT) with thiamethoxam 25WG @ 25g ai ha^{-1} (T3) and imidacloprid 70WG @ 25 g a.i. ha^{-1} (T4) at 15 and 30 days after sowing (DAS) and a combination of seed treatment followed by a foliar spraying (ST+FT) with thiamethoxam (T5) and imidacloprid (T6) at 30 DAS. A standard check insecticide quinalphos 25EC @ 250 g a.i. ha^{-1} as two foliar sprayings (FT) at 15 and 30 DAS (T7) along with an untreated control (T8) were also included in the field experiment.

Both thiamethoxam and imidacloprid were found to be significantly effective than quinalphos against *Amrasca biguttula biguttula* Ishida in okra. All the three methods of application with thiamethoxam and imidacloprid showed equal effectiveness upto 30 DAS. However, both the foliar treatment and the combination of seed treatment followed by a single foliar treatment with thiamethoxam proved to be equally effective throughout the season to *A. biguttula biguttula.*

Thiamethoxam and imidacloprid by all the three application methods (seed treatment, foliar treatment and combination of seed treatment followed by foliar treatment) were equally effective against *Aphis gossypii* Glover upto 25 DAS. From 30 to 50 DAS, two foliar sprayings at 25 g a.i. ha^{-1} revealed a highest reduction of 88.49 per cent in the population of *A. gossypii.* Two foliar sprayings with imidacloprid 70 WDG @ 25 g a.i. ha^{-1} at 15 and 30 DAS recorded the lowest population of *Bemisia tabaci* Gennadius and least leaf damage by

Sylepta derogata Fabricius in okra. Thiamethoxam 25WDG with two foliar sprayings (2 FT) @ 25 g a.i. ha^{-1} at 15 and 30 DAS significantly reduced the shoot and fruit damage by *Earias vitella* Fabricius

With regard to the impact of thiamethoxam and imidacloprid on natural enemies, two foliar sprayings with thiamethoxam at 25 g a.i. ha^{-1} showed highest coccinellid population in the first season. In the second season, seed treatment with thiamethoxam @ 3 g a.i. kg^{-1} indicated the highest population of coccinellids. However, imidacloprid was found to be safer than the standard check quinalphos to coccinellids in both seasons. But the spider population was observed to be relatively less in all the treatments of thiamethoxam and imidacloprid as compared to the untreated control. Thiamethoxam and imidacloprid showed no adverse effect on other predators such as syrphids, chrysoperla and rove beetles in okra field.

Thiamethoxam and imidacloprid indicated phytotonic effects on okra plant for they exhibited significant effects on plant growth parameters. Two foliar sprayings of thiamethoxam significantly increased the plant height, number of leaves, flowers per plant, fruit weight and fruit length. Seed treatment with both thiamethoxam and imidacloprid reduced the days for flower initiation. Terminal residue in fruits was below detectable limit at 15 days after spraying in all the treatments with thiamethoxam and imidacloprid.