Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2018; 6(1): 333-339

Received: 29-11-2017
Accepted: 30-12-2017

Role of neonicotinoids in insect pest management: A review

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Abstract
Neonicotinoids are the most widely used insecticides in the world. They are systemic in action, travelling through plant tissues and protecting all parts of the crop, and are widely applied as seed dressings. Neonicotinoids are registered globally in more than 120 countries and found to be effective against sucking pests. In terms of area treated almost 90% of the use is as seed treatments. Some of these active substances are approved for use as seed treatments (clothianidin), some as foliar applications (acetimiprid and thiacloprid) and some for both (imidacloprid and thiamethoxam). They are nicotinic acetylcholine receptor agonists; they bind strongly to nicotinic acetylcholine receptors (nAChRs) in the central nervous system of insects, 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, so they are selectively more toxic to insects; and present no hazard to mammals; they provide effective pest control and have numerous uses in arable farming and horticulture. They provide an alternative mode of action to organophosphate, carbamates and pyrethroid insecticides. This allows them to play a key role in helping to prevent the buildup of resistance in the pests concerned. These show higher efficacy and used at a lower dosage as compared to other conventional insecticides. There is absence of cross-resistance in neonicotinoids with pyrethroids, carbamates, organophosphates and organochlorines.

Keywords: cross- resistance, lower dosage, neonicotinoides, nAChRs, seed treatments, sucking pests, systemic

1. Introduction

Neonicotinoides, are the newest major class of insecticides, have outstanding potency and systemic action for crop protection against piercing-sucking pests. These were developed in the 1980s, and the first commercially available compound, imidacloprid, has been in use since the early 1990s [13]. Their common names are acetamiprid, clothianidin, dinotefuran, imidacloprid, nitenpyram, thiacloprid, and thiamethoxam. They possess lower mammalian toxicity, less resurgence problems, environmental protection, pest management selectivity and less toxicity to natural enemies [15]. Neonicotinoides are broad-spectrum, systemic compounds exhibit activity against sucking insects (e.g. aphids, whiteflies, leafhoppers) and several species of flies and moths. These are readily absorbed by plants and act quickly, at low doses as compared to other insecticides [27]. They are used primarily as plant systemic, applied to seeds, soil, or foliage; they move to the growing tip and afford long-term protection from piercing-sucking pests e.g., for 40 days in rice [8]. Some organophosphates and methylcarbamates also have good systemic activity but their use is declining due to selection of resistant insect strains and increasing restrictions based on human safety considerations. The expanding importance of crops expressing *Bt* δ-endotoxin encourages neonicotinoid use because the types of pests not controlled by the endotoxin are often those highly sensitive to neonicotinoids [11, 12]. Although crop protection is the major use for neonicotinoids, pest insect control on pets or companion animals is also a significant market. Imidacloprid and nitenpyram are highly effective flea control agents on cats and dogs, and are administered as oral tablets or topical spot treatments [24]. Neonicotinoides are used at lower dosage as compared to conventional insecticides. Each active substance is formulated for use in a range of products. Today approximately 60% 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 [10]. Some of these active substances are approved for use as seed treatments (clothianidin), some as foliar applications (acetimiprid and thiacloprid) and some for both (imidacloprid and thiamethoxam). They are nicotinic acetylcholine receptor agonists; they bind strongly to nicotinic acetylcholine receptors (nAChRs) in the central nervous system of insects, causing nervous stimulation at low concentrations, but receptor blockage, paralysis and death at higher concentrations [30]. Neonicotinoides bind more strongly to insect nAChRs than to those of vertebrates, so they are selectively more toxic to insects [31]. Neonicotinoids are important as they provide an alternative mode of action to organophosphate, carbamates and pyrethroid insecticides. This allows them to play a key role in helping to prevent the buildup of resistance in the pests concerned. Neonicotinoides use has increased steadily, since imidacloprid first came on the market in 1994. 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). For example, in the UK, use as a seed dressing accounted for 91% of all neonicotinoid use in farming in 2011[3]. Globally, 60% 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. However, the widespread adoption of neonicotinoids is partly down to their flexibility of use, for they can be applied in many other ways[10] ; they are commonly used as foliar sprays on horticultural crops such as soft fruits and on some arable crops such as soya, and they are sold 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 [21]. They are commonly used in topical applications on pets such as dogs and cats to control external parasites. Neonicotinoids are relatively safe for use around people, animals and the environment [19] [33]. Neonicotinoides are used on broad spectrum of crops like pome fruits, stone fruits, citrus, grape, horticultural and industrial crops, flower and ornamental plants. Aphids, whiteflies, planthoppers, scale insects, Lepidoptera, soil insects and Colorado potato beetle are included among the target pests [20]. The neonicotinoids have higher selectivity factors for insects versus mammals than most insecticides apart from pyrethroids [34]. Because of their effectiveness and relative safety, neonicotinoids have become one of the fastest growing classes of pesticides used in agriculture as well as in home and garden products [9]. The present review discusses the role of neonicotinoides in pest management.

2. Classification of Neonicotinoids

Neonicotinoids can be classified into one of three chemical groups, the N-nitroguanidines (imidacloprid, thiamethoxam, clothianidin and dinotefuran), nitromethylenes (nitenpyram) and N-cyanoamidines (acetamiprid and thiacloprid). Neonicotinoid compounds with 6-chloro-3-pyridinylmethyl or chloropyridin moiety are referred to as chloropyridinyls / chloronicotinyls/ first generation neonicotinoides. It includes imidacloprid, thiacloprid, nitenpyram, and acetimiprid and were developed between 1984 and 1989 [31]. A second generation of neonicotinoids including clothianidin and thiamethoxam, this neonicotinoides subclass featured as chlorothiazolyl moiety are referred to as chlorothiazolyls (or thianicotinyls) and was developed between 1989 and 1992[14]. A third generation was discovered when it was found that the chloropyridine or chlorothiazole rings could be replaced with (±)-tetrahydro-3- furylmethyl, or furnanicotinyl moiety are referred to as the tefuryl, resulting in Mitsui Chemicals 1994 synthesis of dinotefuran[31,33].

3. Mechanisms of action of Neonicotinoids

Neonicotinoides are structurally distinct from all other synthetic and botanical pesticides and exhibit favorable selectivity. As plant systemic they are increasingly replacing organophosphates and methylcarbamates to control piercing-sucking insect pests, and are also highly effective flea control agents for cats and dogs [30]. They generally have low acute toxicity to mammals, birds, and fish, but display some chronic toxicity in mammals. Neonicotinoids are nicotinic agonists that interact with the nAChR in a very different way than nicotine, which confers selectivity to insects versus mammals [30]. The neonicotinoids are not protonated but instead have an electronegative tip consisting of a nitro or cyano pharmacophore that imparts potency and selectivity, by binding to a unique cationic subsite of the insect receptor. This is in marked contrast to the action of protonated nicotinoids, which require a cation-π interaction for binding to the vertebrate receptor. These differences provide the neonicotinoids with favorable toxicological profiles. The selectivity ratio of neonicotinoides is very high as compared to other class of insecticides; so they possess lower toxicity to mammals, birds and fishes. The neonicotinoids and pyrethroids have higher selectivity factors for insects versus mammals than the organophosphates, methylcarbamates and organochlorines as shown in Table 1[32]. The LD50 value of neonicotionoides is very high as compared to other class of insecticides. The high LD50 value indicates that neonicotinoides are highly toxic to insects and least toxic to mammals. Since they bind at specific site, the post synaptic nAChR, the mode of action is different and hence no records of cross resistance to the carbamates and OP, thus making them important for management of insecticide resistance [31]. And, of course, the major strength of neonicotinoids results from their low mammalian toxicity and favorable safety profile [16, 34].

Table 1: Comparison of neonicotinoids with other classes of insecticides.

Class	LD 50 mg/kg Insects	Rats	Selectivity factor
Neonicotinoides	**2.0**	**912**	**456**
Organophosphates	2.0	67	33
Methylcarbamates	2.8	45	16
Organochlorines	2.6	230	91

4. Market and Economic Success

Neonicotinoids have made a major impact on pest control in a relatively short period of time. Imidacloprid has quickly become the number one selling insecticide in the world. Different waves of plant-protection products entered the market in the early 90s. Expansion of neonicotinoid insecticides has been driven by growth of established products such as imidacloprid as well as newer entrants such as thiamethoxam and clothianidin. Imidacloprid currently accounts for approximately 41.5% of the whole. Imidacloprid come in many forms, including liquids, granules, dusts, and packages that dissolve in water and imidacloprid products may be used on crops, houses, or used in flea products for pets. The launch of neonicotinoids was an immediate economic success. Some four years after its 1991 launch, imidacloprid became the second biggest selling insecticide in the world, with 1995 sales of $360 million (close behind the organophosphate chlorpyrifos [10, 34]. By 1997, sales of the active ingredient (including crop and animal health applications), reached $562 million giving imidacloprid the distinction of being the top-selling insecticide in the world [34]. Global crop-protection-industry news, analysis, and data provider Cropnosis (formerly Wood Mackenzie), confirms imidacloprid's top-selling insecticide status in 2008 as shown in table 2 [22]. The amount of OP insecticides used in the U.S. has declined more than 70% since 2000; from an estimated 70 million pounds to 20 million pounds in 2012. OP usage as a percentage of total insecticide use has decreased from 71% in 2000 to 33% in 2012. The decrease in OP usage reflects a shift in usage to other classes of pesticides (i.e., pyrethroids, neonicotinoids, and other new chemistries) because of the phasing out and use restrictions placed on OP insecticides as a result of pesticide registration review.

5. Utilization of Neonicotinoids

Table 2: Top ten agrochemicals in terms of global scale.

Brand	Active ingredient	Application	Sales billion dollar (2008)
Round up	Glyphosate	Herbicide	8.30
Admire	Imidacloprid	Insecticide	1.28
heritage	Azoxystrobin	Fungicide	1.16
F 500	Pyroclostrobin	Herbicide	1.10
flagship	Thiamethoxam	Insecticide	0.73
Callisto	Mesotrione	Herbicide	0.62
Grammoxone	Paraquat-dichloride	Herbicide	0.60
Flint	Trifloxystrobin	Fungicide	0.60
Horizon	Tebuconazole	Fungicide	0.55
Regent	Fipronil	insecticide	0.53

Neonicotinoid insecticides are active against a wide range of sucking, biting and some chewing insects. The main reasons for the success of the neonicotinoids in plant protection are their high efficacy, selectivity, plant systemicity as well as long-lasting effect and versatile applications. Clothianidin, imidacloprid and thiamethoxam are used as the active substances in seed dressings. These neonicotinoids protect the crops in several ways. The neonicotinoids are used to protect the seeds from being destroyed by insects in the soil and the uptake of the neonicotinoids through the roots and their systemic distribution leads to the entire protection of plants from biting, sucking and chewing insects during growth. Through, these two modes of actions the neonicotinoids are applied in seed dressings. In contrast, thiacloprid and acetamiprid are applied as sprays onto agricultural plants and supply directly with short time protection. In addition to its use in seed dressing's thiamethoxam can also be applied in the form of a spray [28]. Neonicotinoides pesticides are used in over 120 countries and on crops such as vegetables, pomes, nuts, citrus, rice, cotton, maize, potatoes, sugar beets, rapes and soybeans. Neonicotinoides have an endless range of uses because their unique physiochemical properties and translocation rates, combined with residual activity, make them highly effective against sucking and chewing species, including aphids, whiteflies, leafhoppers, plant hoppers, and the Colorado potato beetle [10]. The first neonicotinoid imidacloprid has gained registration for over 140 crop uses in more than 120 countries under the main trade names Confidor and Admire for foliar use and Gaucho for seed treatment [7]. Acetimiprid has been marketed, for example, under the trade name Mospilan and is registered for cotton, vegetables (Assail), potato, orchards for codling moth control, vines, citrus, tea, and ornamentals (Chipco Tristar). In addition, acetamiprid is also of interest for the control of termites and household pests. Thiamethoxam is marketed as Actara for foliar application, as Platinum for soil application, and as Cruiser for seed treatment uses. Today, thiamethoxam is registered for 115 crop uses in at least 65 countries on a wide range of crops such as vegetables, potatoes, rice, cotton, fruit, tobacco, and cereals respectively. Its pest spectrum includes all major sucking insects, as well as some chewing and soil-living pests. Thiacloprid was launched under the trade name Calypso and is active against sucking and chewing pests on crops such as fruit, cotton, vegetables, oilseed rape, cereals, potato, rice, and ornamentals [7]. Besides aphids, various species of beetles, lepidopteron leaf miners, and *C. pomonella* (L.) are controlled. It has a favorable beneficial profile and is bee safe [4]. Therefore, thiacloprid can also be applicated on flowering crops [24]. Clothianidin covers a broad pest spectrum, which resulted in applications as insecticide for seed treatment (Poncho), for soil (Dantotsu), and for foliar use (Dantop). The pest spectrum includes Coleoptera, Diptera, Hemiptera, and some Lepidoptera. The product can be applied on different crops such as rice, cereals, corn, oilseed rape, fruit, potatoes, sugarbeets and vegetables. Dinotefuran launched under the trade name Starkle and is marketed in the United States as Safari in ornamentals and as Venom in fruit, cotton, potatoes, and vegetables. The neonicotinoides insecticides have a high degree of versatility, not seen to the same extent in other chemical classes. Since the insecticide is absorbed by all parts of the plant, it is considered highly systemic and toxic to pests throughout different phases of the plant's lifecycle. The range of application methods includes foliar sprays; irrigation water in drip, drench systems, or in floating box systems; direct soil injection; trunk and bud injection; and also seed treatments [10].

Seed treatments have proven to be a particularly efficient and effective application method which requires less overall insecticide use as a result of neonicotinoid potency. Seed dressings, coatings, and soil treatments are also viewed as far safer to agricultural workers, and may eliminate the need for foliar spraying due to their systemic properties that are translocated throughout the plant, allowing for efficacy against pests from the outset of the growth cycle [10]. New opportunities have been opened up in modern crop protection. Today approximately 60% 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 other [10]. Seed dressing, film coating, pelleting, and multilayer coating allow an environmentally safe and perfect protection of young plants against insect attack. With this method, application of the active ingredient is virtually independent of the weather and can be applied directly at the site of action. The application amount (g of active ingredient per hectare) used per unit area is thereby reduced remarkably. Since neonicotinoides possess good water solubility, they are readily absorbed and translocated by root systems and leaves alike, making these compounds highly systemic, particularly when used as a seed dressing. As a result of these systemic properties, neonicotinoides possess "excellent activity especially against homopteran (i.e. aphids and leafhoppers), coleopteran (i.e. beetle species), dipteran (i.e. flies), and lepidopteran (i.e. leafworms) pests" [32] by penetrating not only the roots and leaves of a sapling, but also affecting the soil around the root zone. This property makes neonicotinoids highly complementary to Bt seeds and crops, which take between 3-6 weeks to build up sufficient Bt levels in emerging seedlings to deter pests, whereas neonicotinoid seed coatings provide immediate efficacy against devastating early-growth-stage pests such as corn rootworm species [34].

6. Efficacy of Neonicotinoides

Neonicotinoides are a unique chemical class for sucking insect pest control owing to their (i) broad spectrum of efficacy, (ii) selective activity as agonists on insect *n*AChRs, (iii) exhibition of long-lasting residual effects, (iv) control of insects resistant to conventional insecticides, (v) high systemicity and excellent plant virus vector control, (vi) versatile application methods, especially in seed treatment and soil application, (vii) Neonicotinoides have an alternative mode of action to other insecticides and so can be used against pests resistant to other insecticides and to help prevent the buildup of resistance. Resistance to the main alternatives to neonicotinoids (pyrethroids and organophosphates) has emerged to a significant degree in pollen beetle (which is a widespread pest of oilseed rape) in France, Poland and Germany. Although resistance in the UK is limited to relatively small pockets of Eastern England, use of foliar neonicotinoides is the recommended strategy for containing resistant communities; (viii) Neonicotinoides insecticides prevent damage to important crops such as cereals, oilseed rape, brassicas and sugar beet from pests such as aphids. When the aphid feeds on the crop it can introduce viruses which cause disease such as barley yellow dwarf virus (affecting cereals) and beet yellow virus (affecting sugar beet). They can have serious effects on crop yields and quality [9].

Field results indicate that multiple foliar spay applications of imidacloprid improved health and increased plant growth even in situations without insect infestations. Imidacloprid treatment led to considerable reduction of yield losses by drought stress compared to other neonicotinoids, as established in a pepper field in Georgia. Water-deficit field studies confirmed the potential of Trimax (optimized imidacloprid formulation) to moderate water stress in plants with an average lint yield increase in cotton of 10% [29].

The experiment was conducted to determine efficacy of four neonicotinoids viz; nitenpyram 10SL, thiacloprid 480SC, imidacloprid 200SL, acetamaprid 20SL and four traditional insecticides such as profenofos 50EC, methidathion 40EC, bifenthrin 10EC, λ-cyhalothrin 2.5EC at their recommended field doses against sucking insect pests of cotton and their natural enemies on cotton variety Bt-121 at a farmers' field in Multan[1]. The data on post spray number of insect per leaf was taken to find difference among treatments. The minimum number of white flies, jassids and thrips were recorded in neonicotinoid treated plots as compared to conventional insecticide treated plots as shown in Table 3. The results showed that nitenpyram, thiacloprid and imidacloprid were safer to natural enemies and toxic for the sucking pests as compared to conventional insecticides. The range of percent survival of the 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) was in neonicotinoids and conventional insecticide treated plots, respectively. In another study imidacloprid and acetamiprid were the most effective against cotton jassid [1, 22]. The side effects of neonicotinoids against nontarget insects especially predators has been demonstrated in the tests under laboratory conditions [18] [2]. The results of a field study have also reported less toxicity of these insecticides for a variety of predators [17].The efficacy of some neonicotinoides was reported against aphid of okra during pre- kharif season of 2010 and 2011. Imidacloprid 17.8 SL @ 50 g a.i. ha-1 was found as a most effective neonicotinoid insecticide against aphid. It recorded least aphid infestation and 84.54 % reduction of population over control. To control aphid population of okra the other two neonicotinoids viz., thiamethoxam 25WG @ 50 g a.i. ha-1 and acetamiprid 20SP @ 40 g a.i. ha-1 were also found at par with imidacloprid and showed better result than acephate 75WP and dimethoate 30EC. Considering incremental cost benefit ratio acetamiprid 20SP @ 40g a.i. ha-1 was found most economic over other neonicotinoids. The experiment also demonstrated that the two rounds of spray of neonicotinoids on okra had no significant impact on the *Coccinellid*s (grubs and adults), *Chrysoperla* and spider population when compared with untreated control plot. However, acephate and dimethoate recorded relatively lowest population of three natural predators like, *Coccinellid*s (grubs and adults), *Chrysoperla* and spider population when compared with untreated control plot. The result showed that acephate was toxic to these natural enemies, while dimethoate also showed toxicity towards them [6].

Table 3: Comparison of mean number of whiteflies, jassids and thrips in various insecticide treatments during the year 2014.

Treatments	Dosage ml/gm/lit	Thrips/ 3 leaves 1DBS	Thrips / 3 leaves		
			1DAS	4DAS	7DAS
Imidacloprid	0.3ml	20.91	8.33	3.08	0.75
Imidacloprid	0.4ml	21.50	7.08	3.16	1.25
Imidacloprid	0.8ml	19.33	7.00	3.75	1.25
Imidacloprid	1.6ml	19.58	6.50	3.91	2.50
Acetamaprid	0.3gm	18.00	8.00	4.00	2.00
Thiamethoxam	0.3gm	19.66	8.70	4.25	2.50
Dimethoate	1.7ml	18.66	12.66	9.16	9.00
Control	------	20.91	20.33	21.41	20.83

Table 4: Bioefficacy of Neonicotinoides against grapevine thrips during 2010.

Treatment s	Common name	Trade name	Group	Dose ml/ acre	White fly	Jassid	Thrips
1	Nitenpyram	Pyramid	Neonicotinoid	1oo	2.33	0.50	1.71
2	Thiacloprid	Talent	Neonicotinoid	50	2.03	0.53	1.76
3	Imidacloprid	Confidor	Neonicotinoid	80	3.01	0.95	1.98
4	Acetamiprid	Rani	Neonicotinoid	125	2.63	0.91	2.66
5	Profenofos	Curacron	Organophosphate	800-1000	3.35	1.00	3.25
6	Methidathion	Supracide	Organophosphate	600-700	2.83	0.87	2.56
7	Bifenthrin	Talstar	Pyrethroid	250	3.46	0.98	2.64
8	Cyhalothrin	Karate	Pyrethroid	325	3.11	1.05	2.48
9	Control	Water			7.90	3.15	5.76

Table 4 shows the results on the reduction of thrip population at 1, 4 and 7 days after spraying. All the four concentrations of imidacloprid 200 SL *viz.* 0.3 ml, 0.4ml, 0.8ml and 1.6ml are found on par with each other in reducing the thrips population at various intervals of observation after spray. At one day after spraying thrips per three leaves were 8.33, 7.08, 7.00 and 6.50, respectively. They were also found on par with other two nicotinoids molecules *viz.* thiamethoxam 25 WG@ 0.3 gm and acetamaprid 20SP@ 0.3 gm which recorded 8.70 and 8.00 thrips per three leaves, respectively. These neonicotinoides are found significantly superior over standard check Dimethoate @1.7 ml, 12.66 thrips. Similar trends were also observed at 4 and 7 days after spraying, in reducing the thrip population [27].

The field experiment was conducted during *rabi* 2011 and 2013 to evaluate the efficacy of different insecticidal treatments against aphid, *Aphis craccivora* Koch, leafhopper, *Empoasca kerri* Pruthi, defoliator, *Spodoptera litura* (Fab.) and pod borer, *Helicoverpa armigera* (Hub.) on black gram. The results showed that seed treatment with thiamethoxam 25 WG @ 3 g/ kg of seed + spray with thiamethoxam 25 WG @ 0.4 g/ l recorded the lowest population of aphids (1.60, 1.45 no. /plant) and leafhoppers (2.36, 2.12 no./ plant) followed by spraying of imidacloprid 17.8 SL @ 0.4 ml/ l with 83.96, 87.45 kg and 66.13, 71.61 per cent reduction over control, respectively after second round of spraying in the fields trials I and II. Indoxacarb 14.5 SC @ 1 ml/ l provided an effective control of *S. litura* and *H. armigera* which recorded 0.04, 0.00 and 0.09, 0.03 nos of larvae/plant at 7th day after the second application in the field trial I and II, respectively, which was at par, with sponsored 45 SC @ 0.4 ml/ l (0.08, 0.07 and 0.13, 0.13 at 7 DAT of second application) but was significantly better than the untreated control. Thus, seed treatment with thiamethoxam 25 WG @ 3 g/kg of seed + spray with thiamethoxam 25 WG @ 0.4 g/ l and indoxacarb 14.5 SC @ 1 ml/ l proved effective against sucking pests and borers of black gram, respectively and can be recommended for their use in black gram ecosystem [5]. The insecticides were demonstrated under the field conditions on the basis of number of BPH per hill, changes in the population of natural enemies and finally the yield. It was clear from the result that the brown plant hopper population did not vary significantly among the treatments before the application of insecticides. At 1 day after spraying the dinotefuran at 30 and 25 g ai. /ha recorded lowest number of BPH per hill followed by imidacloprid and acephate. Upto 15 days after 1st spray dinotefuran at 30 and 25 g ai. /ha maintained the population of brown plant hopper under normal limit. Same trend was noticed after 2nd spray also. Population of brown plant hopper considerably reduced after 1 day of spraying and continued even after 7 days. Lowest population was recorded in dinotefuran at 30 and 25 g ai./ha which are statistically at par throughout the observation. Dinotefuran at 25 and 30 g ai./ha were recorded as the best treatments over imidacloprid and acephate. A predator favourable low BPH and mirid bug ratio was maintained in case of dinetofuan treated plots as compared to imidacloprid and acephate treated plots, that implied its safety to mirid bug. In overall findings, author found that dinotefuran performed very good spectrum of action throughout the seasons against BPH population than the conventional acephate and commonly used neonicotenoid imidacloprid. Dinotefuran showed quick knock down in action and restrained to build up the population of BPH up to harvesting stage. Among the traditional neonicotinoids, imidacloprid showed lower efficacy than dinotefuran. It was evident from the present investigation that dinotefuran 20 SG is effective against *Nilaparvata lugens* at 25 g ai./ha and is very safe to the important predators recorded in rice field [7]. Dinotefuran acts through contact and ingestion and results in the cessation of feeding within several hours of contact and death shortly after. It does not inhibit cholinesterase or interfere with sodium channels. Therefore, its mode of action is different from those of organophosphate, carbamate, and pyrethroid compounds. It appears that dinotefuran acts as an agonist of insect nicotinic acetylcholine receptors, but it is postulated that dinotefuran affects the nicotinic acetylcholine binding in a mode that differs from other neonicotinoid insecticides. It is reported that dinotefuran was highly active on a certain silverleaf whitefly strain which developed resistance against imidacloprid. Neonicotinoid insecticides belong to a new insecticide class which act as competitive inhibitor of nicotinic acetylcholine receptors in the central nervous system. Their systemic property and long residual activity make them ideal insecticides against sucking pests. Dinotefuran is a new furanicotinyl insecticide which represents the third generation of neonicotinoid group. Dinotefuran was developed by Mitsui Chemicals. Dinotefuran was granted Organophosphorus Alternative and Reduced Risk Status by the EPA. In the present study, dinotefuran was found to be quite safe to nymphs and adults of mirid bug (*C. lividipennis*). Dinotefuran 20 SG at 30 and 40 g ai. /ha was proved to be effective against brown plant hopper at 35 locations in India during 2009. It was suggested that due to ever growing insecticide resistance in mosquitoes to commonly used insecticides in many parts of the globe, there is always a need for introduction of new insecticides for the control of resistant vector mosquitoes. The author tested larvicidal and adulticidal efficacies of three neonicotinoids (imidacloprid, thiacloprid and thiamethoxam) against resistant and susceptible populations of *Anopheles stephensi* Liston 1901, *Aedes (Stegomyia) aegypti* Linnaeus, and *Culex quinquefasciatus* Say (Diptera: Culicidae) [32]. The results of topical application on 3-5 day old female mosquitoes indicated that resistant strain of *An. stephensi* registered lower LC50 values than the susceptible strain. Among the three insecticides tested, thiacloprid was found more effective than the other two insecticides. *Culex quinquefasciatus* registered lowest LC50 for imidacloprid than the other two mosquito species tested. In larval bioassays, the LC50 values registered for imidacloprid were in the order of *Cx. quinquefasciatus* <*An. stephensi* (SS) <*An. stephensi* (RR) <*Ae. aegypti*. In case of thiacloprid, the order of efficacy (LC50) was *Cx. quinquefasciatus* <*An. stephensi* (SS) <*An. stephensi* (RR), whereas in case of thiamethoxam, the larvicidal efficacy was in the order of *An. stephensi* (RR) <*An. stephensi* (SS) <*Cx. quinquefasciatus.* The study indicated that insecticide resistant strains of mosquito species tested showed more susceptibility to the three neonicotinoids tested, and the possibility of using neonicotinoids for the control of resistant mosquitoes should be explored. One of the important characteristics of neonicotinoides is that the dosage of neonicotionoides ranges between 75-300ml/g/ha, is very low as compared to other class of insecticides that ranges between 750-2000ml/g/ha [27].

7. Conclusion

Neonicotinoides are new classes of insecticides with unique mode of action as compared to organophosphates, carbamates and synthetic pyrethroides, Since they bind at specific site, the post synaptic nAChR and hence no records of cross resistance to the carbamates, synthetic pyrithroides and OP thus making them important for management of insecticide resistanceso as insecticide resistance is a critical problem facing economic entomologists today, besides novel insecticides are much safer for natural enemies. These are highly toxic to insects as compared to conventional insecticides, besides they provide lower toxicity to mammals. Major impetus for adoption of these chemistries includes human health concerns, environmental protection and pest resistance to OPs, carbamates and pyrethroids. These are used at a lower dosage as compared to other class of insecticides. To delay resistance there is need of careful rotation of novel insecticides. The non-selective organophosphate and pyrethroids insecticides can bring serious problems of reduction in the population of beneficial insects on the crops all over the world. Hence, in order to preserve natural enemies, selective insecticides compatible with biocontrol agents should be available to include in the programs of integrated pest management (IPM). The present studies have shown that neonictinoids can be suitable candidates for inclusion in Integrated Pest Management of sucking insect pests in major cotton growing areas because these have proved comparatively less toxic to predators ac compared to non-selective insecticides. Insecticide resistance in mosquito vectors is a growing concern in many countries, and there is an urgent need for search of new compounds with different modes of action which do not show cross resistance to insecticides being used in the vector control programmes like organochlorines, organophosphates, carbamates and pyrethroids. Absence of cross-resistance in neonicotinoids with pyrethroids, carbamates and organophosphates, and organochlorines makes them potential candidates for use in mosquito control activity.

8. Acknowledgement
Author is highly thankful to SKUAST-K, Srinagar for providing the library, computer and internet facilities.

9. References

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