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A REVIEW ON EFFECTS OF NEW CHEMISTRY INSECTICIDES ON NATURAL ENEMIES OF CROP PESTS

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Abstract: The conservation of beneficial organisms like natural enemies is a fundamental component of any agro-ecosystem. Most of the insecticides being used for combating the insect-pests in cropping systems are causing deleterious effects on the non-target arthropods present in an agro-ecosystem and therefore there arises a need to shift from traditional chemicals to selective novel groups which have minimal side-effects on natural enemies of the pests. These novel groups could be efficiently incorporated into the integrated pest management (IPM) programmes which focus on using those molecules that are reasonably compatible with the natural enemies. The use of such novel chemical insecticides, in combination with an effective natural enemy may provide more comprehensive prophylactic and remedial treatment than single approach. There are several groups of novel insecticides like bacterial fermentation products, diamides, neonicotinoides, phenyl pyrazoles, pyridine azomethines and tetronic and tetramic acid derivatives etc. which could be used in a compatible manner with the biocontrol agents under the IPM programmes. Their use has been documented to be safer to many natural enemies. An extensive review on their selectivity against the important parasitoids and predators of major insect-pests is contained in this paper which would help scholars and farming and scientific community.
Keywords: Novel Insecticides, Natural enemy, Parasitoids, Predators.

Introduction

The most significant factor disrupting biological control of pests in most cropping systems is the use of insecticides (Naranjo, 2001) which has led to negative impacts on natural enemies (Fernande *et al.,* 2010) causing pest resurgence or secondary pest outbreaks. Integrated pest management (IPM) programs emphasize the utilization of chemical and biological control measures to maintain pest populations below economic thresholds (Roubos *et al.,* 2014) with their lower operational impact on agro-ecosystem (Kogan, 1998). It stresses upon using as little pesticides as possible and especially those molecules which are reasonably compatible with the natural enemies (Gonzalez-Zamora *et al.,* 2013). It includes management of insect-pests by methods of control not antagonistic to the beneficial organisms (Degrande *et al.,*

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2002; Devotto *et al.,* 2008). Thus, pesticide selectivity to beneficial insects is a feature that must always be considered in order to screen out the best chemical (Carmo *et al.,* 2009).

The need for more selective insecticides was one of the key themes during the evolution of poison free management of insect-pests (Sparks 2013). A significant advantage of these products is their effectiveness with minimal side-effects on natural enemies of the pests (Bueno and Freitas, 2004; Bacci, 2009) and therefore these beneficials can be conserved using selective insecticides. The use of selective chemical insecticides, in combination with an effective natural enemy may provide more comprehensive prophylactic and remedial treatment than single approach (Gentz *et al.,* 2010). Efforts have been made during the past three decades to develop insecticides with selective properties that act specifically on biochemical sites present in particular insect groups. A number of novel insecticides with unique mode of action were registered during the late 1990s and early 2000s for insect control in agriculture. These insecticides play an important role in IPM of many pests with good efficacy, high selectivity and low mammalian toxicity, which make them attractive replacements for organochlorines, organophosphates, carbamates and pyrethroid insecticides (Cardwell *et al.,* 2005; Ishaaya, 2005).

In this review, an effort has been made to pool the information on the effect of some new chemistry insecticide groups *viz.* bacterial fermentation products, diamides, formamidines, neonicotinoides, oxadiazines, phenyl pyrazoles, pyridine azomethines and tetronic and tetramic acid derivatives (Table 1) on natural enemies. The article thus may help in decision making while selecting a chemical for any insect-pest management programme. For classifying these insecticides for their side effects on the non-target arthropods, the IOBC (International Organisation for Biological Control) classification system (Hassan, 1992) (Table 2) has been followed.

Table 1: Classification and mode of action of new chemistry insecticides as per IRAC (Insecticide Resistance Action Committee) (IRAC, 2015)

Chemical class		**Active ingredients**	**Mode of action**
Bacterial fermentation products	Avermectins, milbemycins	Abamectin, Emamectin benzoate, Lepimectin, Milbemectin	Glutamate-gated chloride channel allosteric modulators
	Spinosyns	Spinetoram, Spinosad	Nicotinic acetylcholine receptor allosteric modulators
Diamides		Chlorantraniliprole, Cyantraniliprole, Flubendiamide	Ryanodine receptor modulators
Formamidines		Amitraz	Octopamine receptor agonists

Neonicotinoides	Acetamiprid, Clothianidin, Dinotefuran, Imidacloprid, Nitenpyram, Thiacloprid, Thiamethoxam	Nicotinic acetylcholine receptor competitive modulators
Oxadiazines	Indoxacarb	Voltage-dependent sodium channel blockers
Phenyl pyrazoles	Ethiprole, Fipronil	GABA-gated chloride channel blockers
Pyridine azomethines	Pymetrozine, Pyrifluquinazon	Chordotonal organ TRPV channel modulators
Tetronic and tetramic acid derivatives	Spirodiclofen, Spiromesifen, Spirotetramat	Inhibitors of acetyl CoA carboxylase

Table 2: Classification system for recognising adverse effects of pesticides on beneficial and non-target arthropods as given by IOBC (Hassan, 1992)

Class	**Category**	**% Mortality**	
		Laboratory studies	**All other studies ***
Class 1	Harmless	< 30%	< 25%
Class 2	Slightly Harmful	30-79%	25-50%
Class 3	Moderately Harmful	80-98%	51-75%
Class 4	Harmful	> 99%	> 75%

Note: *Study types are extended laboratory, semi-field and field tests.

1. Extended laboratory: Performed under simulated natural conditions, such as fluctuating temperatures, using natural substrates and with ample ventilation.

2. Semi-field: Plants treated with toxicant immediately prior to the introduction of natural enemies, e.g., glasshouse or caged field experiments.

3. Field: Plants treated with toxicant with natural enemy populations already present and under completely natural environmental conditions.

Bacterial fermentation products

a) Spinosad: It is a mixture of A and D spinosyns, produced by the actinomycete *Saccharopolyspora spinosa*. This chemical shows stomach as well as contact mode of action (Bret *et al.,* 1997) against a wide range of caterpillars, leaf miners, thrips and foliage-feeding beetles. Although it is sometimes classified as environmentally and toxicologically of reduced risk and usually less harmful to predators but wasp parasitoids are significantly more susceptible to its effects (Williams *et al.,* 2003). Spinosad when tested against larvae of an endoparasitoid, *Hyposoter didymator*, was found to be harmful (Schneider *et al.,* 2004). In another study, it was reported to decrease the survival of first instars of coccinellid beetle, *Harmonia axyridis*. It also extended the time for first instars of *H. axyridis* to become adults, decreased their weight gain, and reduced the fertility (Galvan *et al.,* 2005). Its deleterious effects have also been reported on other natural enemies *viz. Trichogramma pretiosum, Geocoris punctipes*, *Bracon mellitor* and *Telenomus remus* under laboratory conditions. However, it did not affect the numbers of *G. punctipes, Hippodamia convergens* and *Coleomegilla maculata* in the field (Tillman and Mulrooney, 2000). In another study, spinosad was found toxic to the larval parasitoid of pulse beetle, *Dinarmus basalis* (Hymenoptera: Pteromalidae) with LC_{50} value of 0.130 ppm at 24 hours after treatment (Duraimurugan *et al.,* 2014).

b) Avermectin: Avermectins, a novel class of macrocyclic lactones are a mixture of natural products produced by a soil actinomycete, *Streptomyces avermitilis* (Lasota and Dybas, 1991). The mixture of B1a and its lower homologue B1b (Abamectin) is currently in use as agricultural miticide and insecticide (Fisher and Mrozik, 1992). Avermectin was found extremely harmful to parasitoid, *Oomyzus sokolowskii*, but slightly toxic to *Cotesia plutellae* (Shi *et al.,* 2004). When evaluated for its persistence on the egg parasitoid, *T. pretiosum,* it was reported slightly persistent upto 15 days (Nornberg *et al.,* 2011). However, it was reported safe to *Trichogramma atopovirilia* (Pratissoli *et al.,* 2011)**.**

About 59 per cent of literature cited in this review article categorized different bacterial fermentation products in IOBC category of 'harmful to moderately harmful' (Table 3).

Table 3: Effects of bacterial fermentation products on some important natural enemies

Natural enemy	**Stage tested**	**IOBC category**	**Reference(s)**
		Spinosad	
Parasitoids			
Opius concolor	Adult	Harmful[L]	Vinuela *et al.* (2001)
Encarsia formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Hyposoter didymator	Adult	Harmful[L]	Schneider *et al.* (2003)
Hyposoter didymator	Larva	Harmful[L]	Schneider *et al.* (2004)
Diadegma insulare	Adult	Harmful[L]	Cordero *et al.* (2007)
Bracon hebetor	Adult	Moderately harmful[L]	Khan *et al.* (2009)
Trichogramma chilonis	Egg, Larva and Pupa	Slightly harmful[L]	Sattar *et al.* (2011)
	Adult	Harmful[L]	
Trichogramma pretiosum *T. brassicae*	Adult	Moderately harmful[L]	Liu and Zhang (2012)

Bracon nigricans	Adult and Pupa	Harmful^{O}	Biondi *et al.* (2013)
Trichogramma japonicum	Adult	Slightly harmful^{L}	Uma *et al.* (2014)
Predators			
Chrysoperla carnea	Pupa	Harmless^{L}	Vinuela *et al.* (2001)
Podisus maculiventris	Adult	Harmful^{L}	
Typhlodromus pyri	Adult	Harmful^{L}	Miles and Dutton (2003)
Hypoaspis aculeifer, Hypoaspis miles, Phytoseiulus persimilis, Kampimodromus aberrans, Amblyseius andersoni, Amblyseius cucumeris and *Typhlodromus pyri*	Adult	Harmless^{O}	
Amblyseius californicus	Adult	Harmless^{O}	
	Adult and Nymph	Slightly harmful^{L}	Veire and Tirry (2003)
Macrolophus caliginosus	Nymph	Slightly harmful^{L}	
Chrysoperla carnea	Larva	Harmless^{L}	Nasreen *et al.* (2003)
	Adult	Moderately harmful^{L}	Medina *et al.* (2003)
Orius insidiosus	Adult	Harmful^{L}, Harmless^{O}	Studebaker and Kring (2003)
	Nymph	Moderately harmful^{L}, Slightly harmful^{O}	Veire and Tirry (2003)
Orius laevigatus	Nymph	Harmful^{L}	
Neoseiulus longispinosus	Adult	Moderately harmful^{L}	Kongchuensin and Takafuji (2006)
Coccinella septempunctata	Larva	Harmless^{L}	Olszak and Sekrecka (2008)
Chrysopa lacciperda	Larva	Harmful^{L}	Singh *et al.* (2010)
Chrysoperla externa	Adult	Harmless^{L}	Rimoldi *et al.* (2012)
Chrysoperla carnea	Egg and Larva	Harmless^{L}	El-Zahi (2012)
Cycloneda sanguinea	Egg and Larva	Slightly harmful^{L}	Pedroso *et al.* (2012)
Avermectin			
Parasitoids			
Oomyzus sokolowskii	Adult	Extremely harmful^{L}	Shi *et al.,* (2004)
Cotesia plutellae	Adult	Slightly harmful^{L}	Shi *et al.,* (2004); Xia *et al.,* (2008)
Predators			
Euseius stipulates	Mixed population	Slightly to moderately harmful^{O}	Miret and Garcia-Marí (2001)
Emamaectin benzoate			

Parasitoids			
Encarsia Formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Diadegma insulare	Adult	Harmful[L]	Cordero *et al.,* (2007)
Oomyzus sokolowskii	Adult	Moderately harmful[L]	
Bracon hebetor	Adult	Moderately harmful[L]	Khan *et al.,* (2009)
Trichogramma chilonis	Egg, Larva, Pupa and Adult	Slightly harmful[L]	Sattar *et al.,* (2011)
Trichogramma japonicum	Adult	Harmless[L]	Uma *et al.,* (2014)
Predators			
Macrolophus caliginosus	Nymph	Slightly harmful[L]	Veire and Tirry (2003)
Orius laevigatus	Nymph	Harmful[L]	
Orius insidiosus	Adult and Nymph	Harmful[O], Moderately harmful[L]	Studebaker and Kring (2003)
Chrysoperla carnea	Egg and Larva	Harmless[L]	El-Zahi (2012)
Spinetoram			
Parasitoids			
Trichogramma evanescens	Larva	Moderately harmful[L]	Sabry *et al.,* (2014)
Predators			
Chrysoperla carnea	Larva	Slightly harmful[L]	Sabry *et al.,* (2014)
Coccinella septempunctata	Larva	Slightly harmful[L]	
Abamectin			
Parasitoids			
Encarsia Formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Bracon hebetor	Adult	Moderately harmful[L]	Khan *et al.,* (2009)
Predators			
Chrysoperla carnea	Larva	Harmless[L]	Nasreen *et al.,* (2003)
Orius insidiosus	Adult	Harmful[O], Moderately harmful[L]	Studebaker and Kring (2003)
	Nymph	Harmful[O,L]	
Orius laevigatus	Nymph	Harmful[L]	Veire and Tirry (2003)
Amblyseius californicus	Adult and Nymph	Harmful[L]	
Macrolophus caliginosus	Nymph	Slightly harmful[L]	
Neoseiulus longispinosus	Adult	Moderately harmful[L]	Kongchuensin and Takafuji (2006)

Amblyseius andersoni and Euseius stipulates	Adult	Harmless to slightly harmful[O]	Rodrigues and Torres (2008)
Chrysoperla carnea	Egg and Larva	Harmless[L]	El-Zahi (2012)
Orius insidiosus	Egg	Harmful[L]	Moscardini *et al.,* (2013)

L: lab study; O: other studies (field, semi-field etc.)

Diamides

These are ryanodine receptor modulators with wide spectrum of activity. Common insecticides included in this group are: chlorantraniliprole, flubendiamide and cyantraniliprole. Flubendiamide is a phthalic diamide while chlorantraniliprole and cyantraniliprole are anthranilic diamides. These diamides have a favorable ecotoxicological profile and are relatively safe to insect natural enemies (Brugger *et al.,* 2010). Most of these are wide spectrum with flubendiamide mostly targeting the lepidopterans while chlorantraniliprole targeting whitefly, leafminer, beetle and termite species in addition to lepidopterans.

a) Chlorantraniliprole: It is compatible with biocontrol agents and a good fit for industry initiatives to use relatively less toxic pesticides (Larson *et al.,* 2012). It has been reported to show negligible acute contact and oral toxicity to *Cotesia chilonis* and bioagents associated with rice (Huang *et al.,* 2011; Jaafar *et al.,* 2013).

b) Cyantraniliprole: It is the first insecticide to control a cross spectrum of chewing (Lepidoptera) and sucking (Hemiptera) pests. This group of insecticides also possesses the anti-feedant properties (Patel *et al.,* 2014). The formulation Cyazypyr of cyantraniliprole was found safe against the pupal stage of *T. pretiosum*, an important egg parasitoid of *Helicoverpa armigera* (Mandal, 2012). Its effects against *Diaphorina citri* were also investigated by Tiwari and Stelinski, (2013) who reported higher contact toxicity against *D. citri* than its primary parasitoid, *Tamarixia radiate*, emphasizing it as a valuable new tool for rotation into *D. citri* management programs.

c) Flubendiamide: Tohnishi *et al.,* (2005); Kubendran et al. (2006) and Thilagam (2006) found flubendiamide to be least toxic against beneficial arthropods. Sekh et al. (2007) also reported flubendiamide 480 SC @ 24 and 30 g a.i./ ha as soft on the egg parasitoids of yellow stem borer. Similar results were also reported by Chormule et al. (2014) as they also found Flubendiamide 480 SC @ 30 g a.i./ha to be moderately safe to natural enemies of yellow stem borer.

A perusal of literature referred, categorized about 80 per cent diamides in 'slightly harmful to harmless' IOBC category (Table 4).

Table 4: Effects of Diamides on some important natural enemies

Natural enemy	**Stage tested**	**IOBC category**	**Reference(s)**
Chlorantraniliprole			
Parasitoids			
Cotesia chilonis	Adult	Harmless^{L}	Huang *et al.,* (2011)
Cotesia chilonis	-	Harmless^{L}	Jaafar *et al.,* (2013)
Trichogramma japonicum	Adult	Harmless^{L}	Uma *et al.,* (2014)
Predators			
Chrysoperla carnea	Larva	Slightly harmful^{L}	Sabry *et al.,* (2014)
Coccinella septempunctata	Larva	Moderately harmful^{L}	
Cyantraniliprole			
Parasitoids			
Trichogramma pretiosum	Pupa	Harmless^{L}	Mandal, (2012)
Flubendiamide			
Parasitoids			
Trichogramma chilonis	Egg, Larva, Pupa and Adult	Harmless^{L}	Sattar *et al.,* (2011)
Trichogramma japonicum	Adult	Slightly harmful^{L}	Uma *et al.,* (2014)
Predators			
Orius insidiosus	Egg	Harmful^{L}	Moscardini *et al.,* (2013)
Rynaxypyr			
Predators			
Orius insidiosus	Egg	Harmless^{L}	Moscardini *et al.,* (2013)

L: lab study; O: other studies (field, semi-field etc.)

Formamidines

The formamidines are acaricide-insecticides with a novel mode of action, e.g. amitraz, which inhibits the octopamine receptors involved in energy demanding activities in invertebrates, which are modulated by the dopaminergic system. It is used on crops, livestock, and pets. Amitraz at the maximum recommended field concentration and half dose was found to be harmful and one-forth dose was found to be moderately harmful to *Encarsia formosa,* a parasitoid wasp of greenhouse whitefly Chitgar and Ghadamyari, (2012). Gholamzadeh *et al.,* (2012) also observed a high level of toxicity on the adults of *E. formosa* (100% mortality) and its pupae (83.3% mortality). They also recorded significant reduction in the fecundity and longevity of adults.

Most of studies suggest that amitraz is 'harmful to moderately harmful' to natural enemies according to IOBC classification (Table 5).

Table 5: Effects of Formamidines on some important natural enemies

Natural enemy	Stage tested	IOBC category	Reference(s)
Amitraz			
Parasitoids			
Leptomastix dactylopii	Adult	Harmless[L]	Miret and Garcia-Marí, (2001)
Cales noacki	Pupa	Slightly to Moderately harmful[L]	
Lysiphlebus testaceipes	Pupa	Harmless[L]	
Encarsia formosa	Pupa	Slightly to Moderately harmful[L]	Chitgar and Ghadamyari, (2012)
	Adult	Harmful[L]	Gholamzadeh *et al.*, (2012)
	Pupa	Moderately harmful[L]	
Predators			
Euseius stipulates	Mixed population	Harmful[O]	Miret and Garcia-Marí (2001)
Neoseiulus longispinosus	Adult	Harmful[L]	Kongchuensin and Takafuji (2006)

L: lab study; O: other studies (field, semi-field etc.)

Neonicotinoides

In recent years, neonicotinoids have been 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, their molecular target site (Jeschke and Nauen 2008). This group includes a number of insecticides namely, acetamiprid, imidacloprid, thiamethoxam, dinotefuran and thiacloprid etc.

Fonseca et al. (2008) evaluated the selectivity of acetamiprid, thiametoxam and imidacloprid on natural enemies under field conditions and found them selective to the natural enemies belonging to families Araneida and Tachinidae. Thiametoxam represented a larger effect in the first day (DAA) to the families Formicidae and Tachinidae, when mortality rates of 100% and 56%, respectively, were observed, but it was selective to Arachnida. The insecticide imidacloprid was not selective to Tachinidae but it was selective to the occurring spiders. Carvalho *et al.* (2010) evaluated the effects of the chemical insecticides acetamiprid and imidacloprid on the developmental stages of a parasitoid, *T. pretiosum* and reported it as slightly harmful to the parasitization capacity of *T. pretiosum*. More than 50 per cent of literature cited in present paper categorized neonicotinoids in harmful to moderately harmful IOBC class (Table 6).

Table 6: Effects of Neonicotinoids on some important natural enemies

Natural enemy	Stage tested	IOBC category	Reference(s)
Imidacloprid			
Parasitoids			
Cales noacki	Pupa	Moderately harmful[L]	Miret and Garcia-Marí, (2001)
Encarsia Formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Hyposoter didymator	Adult	Moderately harmful[L]	Morales *et al.,* (2006)
	Larva and Pupa	Harmless[L]	
	Pupa	Harmless[L]	Medina *et al.,* (2008)
Chelonus inanitus	Pupa	Harmless[L]	
Trichogramma cacoeciae	Adult	Harmful[L]	Saber, (2011)
Trichogramma japonicum	Adult	Harmless[L]	Uma *et al.,* (2014)
Predators			
Euseius stipulates	Mixed population	Slightly to moderately harmful[O]	Miret and Garcia-Marí (2001)
Rodolia cardinalis	Pupa	Harmful[L]	
Orius insidiosus	Adult and Nymph	Harmful[L], Moderately harmful[O]	Studebaker and Kring (2003)
Orius laevigatus	Nymph	Harmful[L]	Veire and Tirry (2003)
Macrolophus caliginosus	Nympth	Harmful[L]	
Typhlodromus pyri, Typhlodromus phialatus and *Euseius finlandicus*	Adult	Harmless[O]	Cavaco *et al.,* (2003)
Neoseiulus longispinosus	Adult	Harmless[L]	Kongchuensin and Takafuji (2006)
Cycloneda sanguinea	Egg and Larva	Harmful[L]	Pedroso *et al.,* (2012)
Cryptolaemus montruzeiri	Adult and Larva	Moderately harmful[L]	Halappa *et al.,* (2013)
Acetamiprid			
Parasitoids			
Encarsia formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Diadegma insulare	Adult	Slightly harmful[L]	Cordero *et al.,* (2007)
Oomyzus sokolowskii	Adult	Slightly harmful[L]	
Trichogramma japonicum	Adult	Slightly harmful[L]	Uma *et al.,* (2014)

Predators			
Amblyseius californicus	Adult and Nymph	Slightly harmless[L]	Veire and Tirry (2003)
Macrolophus caliginosus	Nymph	Harmful[L]	
Orius laevigatus	Nymph	Harmful[L]	
Neoseiulus longispinosus	Adult	Slightly harmful[L]	Kongchuensin and Takafuji (2006)
Euseius finlandicus	Adult	Slightly harmful[L]	Georgios *et al.,* (2008)
Cryptolaemus montruzeiri	Adult and Larva	Moderately harmful[L]	Halappa *et al.,* (2013)
Thiamethoxam			
Parasitoids			
Encarsia formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Trichogramma japonicum	Adult	Slightly harmful[L]	Uma *et al.,* (2014)
Trichogramma evanescens	Larva	Slightly harmful[L]	Sabry *et al.,* (2014)
Predators			
Amblyseius californicus	Adult and Nymph	Harmless[L]	Veire and Tirry (2003)
Macrolophus caliginosus	Nymph	Harmful[L]	
Orius laevigatus	Nymph	Harmful[L]	
Delphastus pusillus	Adult, Larva and Pupa	Harmful[L]	Torres *et al.,* (2003)
Coccinella septempunctata	Larva	Harmless[L]	Olszak and Sekrecka, (2008)
	Larva	Moderately harmful[L]	Sabry *et al.,* (2014)
Chrysoperla carnea	Larva	Slightly harmful[L]	
Thiacloprid			
Parasitoids			
Encarsia formosa	Adult	Harmful[L]	Veire and Tirry (2003)
Predators			
Macrolophus caliginosus	Nymph	Harmless[L]	Veire and Tirry (2003)
Orius laevigatus	Nymph	Harmful[L]	
Dinotefuran			
Predators			
Neoseiulus longispinosus	Adult	Harmless[L]	Kongchuensin and Takafuji (2006)

L: lab study; O: other studies (field, semi-field etc.)

Oxadiazines

Oxadiazine insecticides block the sodium channels in insect nerve cells, causing lepidopteran larvae to stop feeding which become paralyzed and die within 2-5 days. Indoxacarb is a promising new pesticide belonging to this group, having strong field activity against lepidopteran pests. Ruberson *et al.,* (1999) tested indoxacarb for its toxicity against *C. rufilabris*, *O. insidiosus*, *G. punctipes*, *T. pretiosum* and *Cotesia marginiventris* and reported no adverse effects on any of these species. Galvan *et al.,* (2005) examined the effects of indoxacarb on survival, development, and reproduction of *H. axyridis* and observed a decrease in survival of first instars and adults and reduced fecundity of females.

More than 60 per cent of literature referred in this article classified indoxacarb in the category of 'slightly harmful to harmless' to different biological control agents (Table 7).

Table 7: Effects of Oxadiazines on some important natural enemies

Natural enemy	Stage tested	IOBC category	Reference(s)
Indoxacarb			
Parasitoids			
Encarsia Formosa	Adult	Harmful^{L}	Veire and Tirry (2003)
Diadegma insulare	Adult	Harmful^{L}	Cordero *et al.,* (2007)
Oomyzus sokolowskii	Adult	Moderately harmful^{L}	
Bracon hebetor	Adult	Moderately harmful^{L}	Khan *et al.,* (2009)
Trichogramma chilonis	Egg	Harmless^{L}	Sattar *et al.,* (2011)
	Larva, Pupa and Adult	Slightly harmful^{L}	
Trichogramma pretiosum and T. brassicae	Adult	Harmless^{L}	Liu and Zhang, (2012)
Trichogramma japonicum	Adult	Harmless^{L}	Uma *et al.,* (2014)
Predators			
Amblyseius californicus	Adult and Nymph	Harmless^{L}	Veire and Tirry (2003)
Macrolophus caliginosus	Nymph	Slightly harmful^{L}	
Orius laevigatus	Nymph	Harmful^{L}	
Orius insidiosus	Adult	Moderately harmful^{L}, Slightly harmful^{O}	Studebaker and Kring (2003)
	Nymph	Harmful^{L}, Harmless^{O}	
Chrysoperla carnea	Larva	Harmful^{L}	Nasreen *et al.,* (2003)
Neoseiulus longispinosus	Adult	Slightly harmful^{L}	Kongchuensin and Takafuji (2006)
Chrysopa lacciperda	Larva	Harmful^{L}	Singh *et al.,* (2010)
Chrysoperla carnea	Egg and Larva	Harmless^{L}	El-Zahi (2012)

L: lab study; O: other studies (field, semi-field etc.)

Phenyl pyrazoles

Phenyl pyrazoles include fipronil which is a relatively new insecticide that controls a broad spectrum of insects at low field application rates. It is a “new generation” insecticide because its mode of action i.e. interference with the normal function of GABA-gated channels (Gunasekara *et al.,* 2007). The toxicity of fipronil used in vegetable fields to the larvae of diamondback moth, *Plutella xylostella* and its two major parasitoids, *C. plutellae* and *O. sokolowskii* was evaluated by Shi *et al.,* (2004). Fipronil was recorded to cause mortality within 24 h and it showed differential toxicity to the two parasitoids. Huang *et al.,* (2011) observed very high insecticidal effect of fipronil to populations of *C. chilonis*. The study conducted by Jaafar *et al.,* (2013) to investigate the effects of fipronil against spider and insect abundance in a rice ecosystem showed a significant reduction of natural enemy populations in fipronil treatments.

About 69 percent literature cited suggests that fipronil is ‘harmful to moderately harmful’ to various natural enemies (Table 8).

Table 8: Effects of Phenyl pyrazoles on some important natural enemies

Natural enemy	**Stage tested**	**IOBC category**	**Reference(s)**
		Fipronil	
Parasitoids			
Cotesia plutellae, *Oomyzus sokolowskii*	Adult	Moderately harmful[L]	Shi *et al.,* (2004)
Hyposoter didymator	Larva and Pupa	Harmful[L]	Morales *et al.,* (2006)
	Adult	Moderately harmful[L]	
	Pupa	Moderately harmful[L]	Medina *et al.,* (2008)
Chelonus inanitus	Pupa	Slightly harmful[L]	
Trichogramma japonicum	Adult	Harmless[L]	Miles and Dutton, (2003)
Predators			
Chrysoperla carnea	Larva	Harmless[L]	Nasreen *et al.,* (2003)
	Adult	Harmful[L]	Medina *et al.,* (2003)
Orius insidiosus	Adult	Harmful[O], Moderately harmful[L]	Studebaker and Kring (2003)
	Nymph	Harmful[O,L]	
Neoseiulus longispinosus	Adult	Moderately harmful[L]	Kongchuensin and Takafuji (2006)
Chrysopa lacciperda	Larva	Harmful[L]	Singh *et al.* (2010)

L: lab study; O: other studies (field, semi-field etc.)

Pyridine azomethines

Pymetrozine is a pyridine azomethine active primarily against sucking insects such as aphids and whiteflies. Its mode of action is not fully understood, but it differs from other insecticide groups. It interferes with feeding behaviour, resulting in the complete cessation of feeding within hours of contact. Torres *et al.,* (2003) studied the toxicity studies of pymetrozine on cotton aphid parasitoid, *Aphelinus gossypii* and whitefly predator, *Delphastus pusillus*. The results revealed that parasitoid emergence was not affected while it was safer against whitefly predator complex also. Pyriproxyfen is another pyridine-based pesticide which is found to be effective against a variety of arthropods. It is classified as harmful for larvae of *Cryptolaemus montrouzieri* due to its acute effect on pupal mortality. The adults of *C. montrouzieri* when fed with pyriproxyfen-treated prey exhibited increased fecundity but no eggs hatched. Moreover, the larvae fed on pyriproxyfen-treated prey did not reach the adult stage (Planes *et al.,* 2013).

Most of the literature cited (89%) in the present review categorized pymetrozine in ‘slightly harmful to harmless’ category of IOBC (Table 9).

Table 9: Effects of Pyridine azomethines on some important natural enemies

Natural enemy	Stage tested	IOBC category	Reference(s)
Pymetrozine			
Parasitoids			
Encarsia Formosa	Adult	Harmless^{L}	Veire and Tirry (2003)
Aphelinus gossypii	Larva and Pupa	Harmless^{L}	Torres *et al.,* (2003)
Hyposoter didymator	Larva and Pupa	Harmless^{L}	Morales *et al.,* (2006)
	Adult	Slightly harmful^{L}	
Predators			
Amblyseius californicus	Adult and Nymph	Harmless^{L}	Veire and Tirry (2003)
Macrolophus caliginosus	Nymph	Slightly harmful^{L}	
Orius laevigatus	Nymph	Moderately harmful^{L}	
Delphastus pusillus	Adult, Larva and Pupa	Harmless^{L}	Torres *et al.,* (2003)
Orius insidiosus	Egg	Slightly harmful^{L}	Moscardini *et al.,* (2013)

L: lab study; O: other studies (field, semi-field etc.)

Tetronic and tetramic acid derivatives

Spirodiclofen was introduced as a tetronic acid derivative and the first cyclic ketoenol, acaricide with a wide spectrum and a novel mode of action i.e. inhibition of acetyl-CoA-carboxylase. Soon after, spiromesifen, spirocyclic phenyl-substituted tetronic acid derivative, was introduced as acaricide and insecticide intended for control of phytophagus mites and whiteflies. Spirotetramat, another tetramic acid derivative, and the third member of the ketoenol group, was recently commercialised as an insecticide efficient against whiteflies, leaf aphids and other harmful homopterans (Dejan *et al.,* 2011).

a) Spiromesifen: The growth inhibiting mode of action of spiromesifen i.e. inhibition of lipogenesis and acetyl CoA-carboxylase in particular (Nauen *et al.,* 2003) may explain its low toxicity on non-target organisms. Side effects of spiromesifen on the parasitoid, *Eretmocerus mundus*, and minute pirate bug, *Orius laevigatus*, the key natural enemies for *B. tabaci* control, were evaluated by Bielza *et al.,* (2009) and they observed that spiromesifen had favourable selectivity to *O. laevigatus* and *E. mundus* and thus its use would complement the biological control of *B. tabaci*. Spiromesifen was found the most promising acaricide for managing the two-spotted spider mite, *Tetranychus urticae* when used in combination with the predaceous mite, *Neoseiulus californicus* (Sato *et al.,* 2011)**.**

b) Spirotetramat: Spirotetramat is another systemic insecticide which is an inhibitor of lipid biosynthesis. The lethal and sublethal side effects of spirotetramat on adults and larvae of *Cryptolaemus montrouzieri* were evaluated by Planes *et al.,* (2013) under laboratory conditions and found safe. When directly applied on larvae and adults of *C. montrouzieri*, it did not affect its survival, longevity, fecundity, egg hatching, and offspring survival.

Most of tetronic and tetramic acid derivatives were found ‘harmless’ to natural enemies according to the literature referred in the present review chapter (Table 10).

Table 10: Effects of Tetronic and tetramic acid derivatives on some important natural enemies

Natural enemy	**Stage tested**	**IOBC category**	**Reference(s)**
Spirodiclofen			
Predators			
Coccinella septempunctata	Larva	Harmless^{L}	Olszak and Sekrecka, (2008)
Amblyseius andersoni and *Euseius stipulates*	Adult	Slightly to moderately harmful^{O}	Rodrigues and Torres (2008)
Spiromesifen			
Parasitoids			
Eretmocerus mundus and *Orius laevigatus*	Adult	Harmless^{O}	Bielza *et al.,* (2009)
Spirotetramat			
Predators			
Cryptolaemus montrouzieri	Adult and Larva	Harmless^{L}	Planes *et al.,* (2013)

L: lab study; O: other studies (field, semi-field etc.)

Conclusion

Based on the above review on the effects of new chemistry insecticides on natural enemies of crops it can be concluded that there are certain insecticides which are not much harmful to natural enemies and can be integrated in the IPM programmes. It is necessary to get accurate scientific evidences of the fate of natural enemies due to use of insecticides under the actual field conditions. Although studies have been conducted in this field under laboratory conditions but still elaborate and extensive field evaluations are urgently required to moderate the most efficient ones at field level so that biological control agents are conserved and sustainable poison free agriculture is possible with stringent technologies in economic crops.

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