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An overview of insecticides and acaricides with new chemistries for the management of sucking pests in vegetable crops

MH Kodandaram*, Yengkhom Bijen Kumar, AB Rai and B Singh

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Abstract

Vegetable production is facing enormous challenge to meet the future demands of growing population in India. Sucking pests are one of the major threats and cause considerable economic damage to vegetable cultivation. Many of the sucking pests like whitefly, thrips, aphids, mealybugs and mites not only cause damage by direct feeding, most of them act as vector for several plant pathogenic viruses. Coventional insecticides or acaricides are extensively used to control the sucking pests but most of them have failed due to lower efficacy, development of high folds of resistance and resurgence of the pests. Modern insecticides or acaricides with green chemistries having novel biochemical target sites are available to combat the menace of sucking pests in vegetable crops. The new products have more favourable mammalian *vs* insect selectivity and can be a suitable component of integrated pest management (IPM) and resistance management programmes in vegetable crops. This paper gives an overview of the innovotaive products launched over past one decade and their propsects in future vegetable pest control.

Key words: Vegetables, insecticides, acaricides, new chemistries, mode of action, sucking insect pests.

Introduction

Vegetables are important constituents of Indian agriculture and nutritional security owing to their short duration, high yield, nutritional richness, ability to generate employment and can be good source to double the farmers income. Currently, India produces 162.90 million tonnes of vegetables covering 9.40 million hectares area with an average productivity of 17.40 t/ ha (Anonymous, 2015). However, inspite of remarkable growth in production and productivity of vegetables, the Indian vegetable sector is still facing several constraints. Biotic stresses are one of the major threats to sustainable vegetable production in India. Among various biotic stresses, sucking pests like whitefly, thrips, aphids, mites, mealybugs, leafhopper, bugs and mite have become major limiting factor in economic productivity of vegetable production in India (Rai *et al*. 2014). Apart from direct feeding damage, most of the sucking pests acts as vector of sevral plant pathogenic viruses. Presently, management of sucking pests in vegetable crops rely heavily on the use of conventional insecticides or acaricides belonging to organophosphates, carbamates and synthetic pyrethroids.

Neverthless, pesticides have played a greater and immense role in vegetables production. The current consumption of pesticide in vegetable crops is estimated to be about 13-14 % of total pesticides used in the country of which insecticides account for two-thirds of total pesticides used (Kodandaram *et al*. 2013). Among different pesticides, insecticides and acaricides remain as an integral part of sucking pest control and integrated pest management (IPM) programs in several vegetable crops. In the last 3-4 decades, extensive use of conventional insecticides and acaricides has resulted in high folds of insecticide resistance, resurgence of sucking insect pests, out-break of secondary or minor insect pests, high level of objectionable pesticide residues, adverse effect on environment and non-target organisms. Several new generation molecules with green chemistry have been developed and introduced for sucking pest control (Table 1). Recently, Kodandaram *et al.* 2010 reviewed on novel insecticides for insect pests in vegetables and Van Leeuwen *et al.* 2015 on recent acaricides for the control of phytophagous mites. Most of the new chemistries have unique mode of action and targets a variety of new and under-utilized biochemical sites in the insects. With the introduction of these new molecules, there is paradigm shift in the use of insecticides or acaricides where the quantities of new

ICAR-Indian Institute of Vegetable Research, Varanasi 221 305, Uttar Pradesh, India.
*Email: kodandaram75@gmail.com

molecules and their formulation required per hectare is very less than the conventional ones. It is important for grower or producers to know about the use of these new chemistries, their mechanism of action, target site, lable claim, pre-harvest interval (PHI) and maximum residue limits (MRL) in different vegetable crops in India. Some of the new molecules and combination products introduced for control of sucking pests in vegetable crops over past one decade is briefly described in this paper.

Flupyradifurone

Flupyradifurone belongs to a new class of chemistry, the butenolide group. It acts as nicotinic acetylcholine receptor agonist. The discovery of flupyradifurone resulted from the complex structure of the stemofoline alkaloid, isolated from Asian plants belonging to the Stemonaceae family (Jeschke *et al*. 2015). It has high level of efficacy against wide range of sucking insect pests *viz*., aphids, leafhoppers, psyllids, scales, thrips and whiteflies. Due to adult knockdown effects it controls nymph and egg stages of sucking pests. Flupyradifurone acts reversibly as an agonist on nicotinic acetylcholine receptor on insect. Its mode of action differs structurally from known agonists like neonicotinoid insecticides and sulfoxaflor, thus the flupyradifurone is assigned to separate chemical group, butenolide group with code 4D in the IRAC mode of action classification (Nauen *et al*. 2015). A unique property of this new molecule is its strong and rapid feeding cessation effect which is active via both ingestion and contact. The systemic and translaminar action make it suitable for both foliar spray and soil treatment in various crops. This new molecule is known

Table 1. Insecticides and acaricides with new chemistries for control of sucking pests in vegetable crops

Sl. No	Insecticide Group	IRAC# Code	Target Site	Mode of Action	Active Ingredients/ Common Name
1.	Butenolides	4D	Nerve	Agonists of nicotinic acetylcholine receptor (nAChR)	Flupyradifurone
2.	Sulfoximine	4C	Nerve	Agonists of nicotinic acetylcholine receptor (nAChR)	Sulfoxaflor
3.	Pyridine-carboxamide	9C	Nerve	Modulators of chordontal organs	Flonicamid
4.	Diamide	28	Nerve and Muscle action	Ryanodine receptor modulators	Cyantraniliprole
5.	Tetronic and tetramic acid derivatives	23	Lipid synthesis	Inhibitors of acetyl CoA carboxylase	Spiromesifen, Spirotetramat
6.	Thiourea Insecticides	12A	Energy Metabolism	Inhibitors of mitochondrial ATP synthase	Diafenthiuron
7.	Pyrrole Insecticides	13	Energy Metabolism	Uncouplers of oxidative phosphorylation via disruption of proton gradient	Chlorfenapyr
8.	Spinosyns	5A	Nerve	Nicotinic acetylcholine receptor (nAChR) allosteric activators	Spinosad , Spinetoram
9.	Juvenile hormone mimics	7 C	Growth Regulation	Disrupt and prevent metamorphosis	Pyriproxyfen
10.	Mite Growth Inhibitor	10A &10B	Growth Regulation	Regulates the growth of mite	Hexthiazox, Flufenzine (Diflovidazin), Etoxazole
11.	Beta-ketonitrile derivatives	25A	Respiration Targets	Mitochondrial complex II electron transport inhibitors	Cyflumetofen
12.	METI Acarcides	21A	Energy Metabolism	Mitochondrial complex I electron transport inhibitors.	Fenpyroximate, Fenzaquin, Tolfenpyrad
13.	Bifenazate	20D	Respiration Targets	Mitochondrial complex III electron transport inhibitors	Bifenazate
14.	Avermectins	6	Nerve	Glutamate-gated chloride channel modulators	Emamectin Benzoate Milibimectin
15.	Benzoylureas	15	Growth Regulation	Chitin biosynthesis Inhibitors type 0	Flufenoxuron
16.	Chitin Synthesis Inhibitors	16	Energy Metabolism	Chitin biosynthesis Inhibitors type I	Buprofezin
17.	Neonicotinoids	4A	Nerve	Agonists of nicotinic acetylcholine receptor (nAChR)	Imidacloprid, Acetamiprid, Thiamethoxam, Thiacloprid
18.	Phenylpyrazoles	2B	Nerve	GABA gated chloride channels antagonists	Fipronil
19.	Sufite Ester Acaricides	12C	Energy Metabolism	Inhibitors of mitochondrial ATP synthase	Propargite

(Source: Kodandaram *et al.* 2010, 2013 and http//www.irac-online.org)

IRAC: Insecticides Resistance Action Committee

to have minimal impact on beneficial arthropods and has an good safety profile to humans, honey bees and bumblebees and environment and is a perfect fit for IPM programmes (Nauen *et al.* 2015). It is also considered to be alternative to imidacloprid and a bee friendly product with no bloom (application) restrictions. Registration of flupyradifurone in India is under process. Its usage rate is 200-250 g ai/ha against whitefly and leafhopper in okra (unpublished data).

Sulfoxaflor

The sulfoximines are a new class of insecticides. They have broad spectrum of activity against sucking insects pests and the structure activity relationships are different from other nicotinic acetylcholine receptors (nAChR) agonists such as the neonicotinoid insecticides (Sparks *et al.* 2013). Sulfoxaflor is the first insecticide developed from the sulfoximine insecticide class (Zhu *et al.* 2010). It is found effective against a wide range of sucking pests like whitefly, aphids, leafhopper and mirid bugs. Sulfoxaflor acts at insect nicotinic acetylcholine receptors (nAChRs) and its mechanism of action is different from other insecticides acting at nAChRs. Further, sulfoxaflor lacks cross-resistance against the insect strains that are highly resistant to imidacloprid and other neonicotinoids (Babcock *et al.* 2011). The IRAC group code for sulfoxaflor is 4C. The unique biological properties of this sulfoxime insecticide shows its potential as an important novel tool for managfement of sucking insect pests. The field use rates range from 12 to 150 g a.i./ha depending on the crop, pest and population level. This new molecule is yet to be registred in India.

Flonicamid

Flonicamid is a selective insecticide, and belongs to the pyridinecarboxamide group, a novel class of chemistry that exhibits good bio-efficacy for controlling different aphid species, whitefly (*Bemisia tabaci*), yellow thrips (*Scirtothrips dorsalis*), leafhopper (*Amrasca biguttula biguttula*), planthoppers, plant bugs and psyllid (Morita *et al.* 2014). The main insecticidal mechanism of flonicamid is starvation due to the inhibition of stylet penetration into plant tissues (Morita *et al.* 2007). Although the insecticidal properties of flonicamid seem to resemble those of pymetrozine, but the mode of action of flonicamid is different from that of pymetrozine. IRAC group code for flonicamid is 9C. Foliar application of flonicamid at 75 g a.i/ha was found effective in controlling the sucking insect pests like leafhoppers (*A.biguttula biguttula*) and whitefly (*B. tabaci*) with low risk of acute toxicity when applied in okra assuring food safety (Kodandaram *et al.* 2017). Moerover, flonicamid has a very favorable ecotoxicological profile and does not have any major negative impact on beneficial arthropods and mites (Hancock *et al.* 2003). The usage rate of flonicamid 50 WG is 50-100 g ai/ha and vary with crop and pest.

Cyantraniliprole (Cyazypyr)

It is a second generation anthranilic diamide insecticide having excellent insecticidal efficacy at low use rates for both borer and sucking insect pests. It is known to control whiteflies, aphids, thrips and psyllids (Thomas Selby *et al.* 2013). The target crops are fruiting vegetables and cucurbits. It has contact, systemic and translaminar activity and suitable for soil application also. This new diamide insecticide selectively binds to the ryanodine receptors (RyRs) in the insect muscle cells, results in activation of RyRs and causing an uncontrolled release and depletion of Ca^{+2} from internal stores which leads to muscle paralysis and death (Cordova *et al.* 2006 and Sattelle *et al.* 2008). The IRAC group code for cyantraniliprole is 28A. The translaminar activity makes it suitable for soil application. Highly suitable for green house vegetable crops. Cyantraniliprole proved to be highly effective against major pests in brinjal and offers a good option as a new tool in strengthening integrated pest management(IPM) (Kodandaram *et al.* 2015). Along with good pest control it also increases the crop vigour and yield. Cyzapyr is available as 10.26 OD and the dosage for different sucking insects is 90 g a.i./ha.

Spiromesifen

Spiromesifen is first molecule to be introduced in the tetronic acid derivatives, having excellent miticide and insecticidal activity (Nauen *et al.* 2003). It has good efficacy against whiteflies *Bemisia tabaci*, *Trialeurodes* spp. (Liu, 2004). In addition to whitefly, it is more effective against spider mites such as *Tetranychus* spp., *Panonychus* spp., *Oligonychus* sp and tarsonemid mites like *Polyphagotarsonemus latus* and eriophyd mites like *Aculops lycopersici* (Elbert *et al.* 2005). It is also reported to suppress some species of thrips such as *Scirtothrips dorsali*, *Thrips palmi* and *Thrips tabaci* in vegetables. Spiromesifen also found active against juvenile stages of insect and has a strong transovarial action on whitefly and mite and by.The mechanism of action of spiromesifen is inhibition of enzyme (Acetyl Co A carboxylase enzyme) in lipid biosynthesis or metabolism. The IRAC group code for this insecticide is 23A (Bretschneider *et al.* 2003). Novel mode of action and lack of cross resistance to other commercial products make spiromesifen as a valuable tool for mite, whitefly and other sucking pests resistance management. Spiromesifen can be an excellent resistance management tool in combination or rotation strategies for managing whitefly resistance to insecticides (Nauen and Konanz, 2005). Because of its high selectivity, good residual activity, minimal risk to pollinators and predatory mites (Nicolaus *et al.* 2005 and Bielza *et al.* 2005) combined with a novel mode of action make spiromesifen as an excellent new tool for many integrated pest management (IPM) programs. It is registered for use in brinjal, chilli, tomato and okra. Available as 22.9 SC and recommended dose is 96 -150 gm a.i/ha.

Spirotetramat

It is third new insecticide of tetramic acid derivatives which shows excellent efficacy against aphids, mealybugs, psyllids, scales, thrips and whiteflies in cabbage, brinjal, pepper, tomato, cucurbits, melons, potato and other tuberous and corm vegetables(Nauen *et al.* 2008) . Juvenile stages are highly susceptible and gives good control of hidden pests and protects new shoots appearing after foliar application. It is considered as alternative to the neonicotinoids and Insect Growth Regulators (IGRs). It has good 2- way systemic action, translocates upward and downward within plants. In addition to foliar spray it can be applied as chemigation. The mode of action is inhibition of enzyme (Acetyl Co A carboxylase enzyme) in lipid biosynthesis or metabolism (Bretschneider *et al.* 2003). The IRAC group code for this insecticide is 23A. Spirotetramat can be a good rotation partner with other existing products in resistance management strategies for sucking pests (Elbert *et al.* 2008). Its potential impact on different ecosystems is favourable with less eco-toxicological profile (Van Waetermeulen *et al.* 2007). The overall profile of spirotetramate make it a highly effective tool for the management of sucking pests in vegetable crops. It is recently registred in India for use and the field rate in okra and brinjal is 90 g a.i./ha against whitefly (Unpublished report).

Diafenthiuron

Diafenthiuron is a proinsecticide and has good biological propterties that is not found in other insecticide classes. It controls sucking pest complex like whitefly, aphid, leafhoppers and also tarsonemid and tetranychid mites (Ishaaya *et al.* 1993). It is known to disrupt oxidative phosphorylation by direct inhibition of mitocontrial ATP synthase (complex V) involved in energy metabolism. The IRAC group code is 12A. Because of its unique mechanism of action, it has no cross resistance with any other existing insecticides or acaricides being used against *Bemisia tabici, Aphis gossypi* (Denholm *et al.* 1995). Though it has no systemic action yet it displays translaminar activity. Its unique chemical class, novel mode of action, biological spectrum, translaminar activity, high selectivity towards beneficial insects and lack off cross resistance with other conventional and new insecticide, makes it as an important active ingredient in protection of many vegetable crops. Diafenthiuron can be an important tool in rotational spray regimes, in any IPM and IRM programs. It is available as 50 WP and the recommended dose is 300 g a.i./ha in brinjal and chilli.

Chlorfenapyr

Chlorfenapyr is a pyrrole insecticide obtained from a natural product, dioxapyrrolomycin, isolated from a strain of *Streptomyces fumanus (Addor et al.* 1992). Chlorfenapyr is active against many species of mites and thrips infesting different vegetable crops (Hunt and Treacy, 1998). It has both stomach and contact action against the target pest. Though chlorfenapyr exhibits a good translaminar activity in plants but it has a very limited systemic and ovicidal action. Chlorfenpyr inhibits oxidative phosphorylation by disrupting the proton gradient in mitochondrial membranes and impairs the ability of the mitochondria to produce ATP. This further leads to destruction of cells and death of the affected pest (Black *et al.* 1994; Hunt and Treacy, 1998). Chlorfenapyr was found to be the most effective gainst yellow mite (*Polyphagotarsonemus latus*) and thrips (*Scirtothrips dorsalis*) in chilli (Halder *et al.* 2015). The IRAC group code is 13A. It is available as 10% SC formulation and recommended dose is 75-100 g a.i/ha.

Spinosad

Spinosad is an insecticide product derived from fermentation of a naturally occurring soil actinomycete, *Saccharopolyspora spinosa*. It contains two insecticidal components, spinosyns A and D, present in an approximately 85:15% ratio in the final product (Kirst *et al.* 1992). Spinosad is most potential and powerful insecticides for controlling the selective insects in vegetables cultivated in greenhouses (Schoonejans and van der Staaij, 2001). It is highly effective against thrips and has good contact and stomach action. It acts at nicotinic acetylcholine and gamma amino butyric acid (GABA) receptors of the insect nervous system (Salgado and Sparks, 2005) and has no cross resistance to other known insecticides. The IRAC group code is 5A. It is found safer to beneficial arthropods, has favorable environmental profile and low mammalian toxicity. The unique mechanism of action, favorable ecotoxicological profiles make this novel insecticide a useful tool in integrated pest management (IPM) programs in vegetables (Salgado and Sparks, 2005). The field recommended dose of spionsad 45 SC for control of thrips in chilli is 73 g a.i/ha with waiting period of 3 days.

Spinetoram

Spinetoram is a second generation insecticide of the spinosyn class, derived from fermentation of *Saccharopolyspora spinosa*, which is followed by modification of chemical to create a unique active ingredient (Sparks *et al.* 2008). The chemical modifications make spinetoram more effective than spinosad against insect pest species and improves its long lasting control. Spinetoram has broad spectrum of acativity against insect pests in a variety of vegetable crops and exhibits excellent translaminar activity. It has good activity against wide range sucking insects pest like thrips and psyllids (Crouse *et al.* 2007). Spinetoram has good potential in desert grown leafy vegetables and melons. It is used as foliar spray or soil application with residual impact for 10-15 days. The IRAC group code is 5A. Low field rates, good toxicological profile aganist non target arthropods and favourable environmental profile makes it a very promising component in vegetable pest control. It is recently registered in India for use in chilli against thrips.

Pyriproxyfen

Pyriproxyfen is a pyridine compound that acts as juvenile hormone mimics and affects the hormonal balance in insects, which leads to strong suppression of embryogenesis, metamorphosis and adult formation (Ishaaya and Horowitz, 1992 ; Ishaa-ya *et al.* 1994). The IRAC group code is 7C. It is most effective on late larval instars, nymphs and early pupal stages when juvenile hormone is normally low. It is considered as a leading insecticide for control of whitefly (Ishaaya and Horowitz,1995) and scale insects (Peleg, 1988). Because of its persis-tence and efficacy, pyriproxyfen has been extremely effective in controlling scale and insects that have developed resistance to organophosphate insecticides. Although high resistance to pyriproxyfen in *B. tabaci* has evolved in some areas, but it remains as an important component for controlling whiteflies (Horowitz *et al.* 2002). It is safer for hy-menopterous parasites than organophosporus insecticides. Pyriproxyfen is toxic to crustaceans, limiting its use around water bodies. It is registred in India and used @ 50 g a.i./ha in chilli crop against whitefly and aphids.

Hexythiazox

Hexythiazox is an broad spectrum acaricide having ovicidal, larvicidal and nymphicidal activity against mites, thrips and leafhoppers and is applied at any stage of plant growth from budding to fruiting (Yamada *et al.* 1987). It is widely used in controlling many phytophagous mites in vegetables crops and it has special affinity towards tetranychid and teneuipalpidae mites . It is a mite growth inhibitor targeting chitin synthase (Van Leeuwen *et al.* 2015). The IRAC group code is 10A. It is highly persistent and toxic to fish and other aquatic invertebrates. It is available as 5.45 % EC and recommended dose is 15-25 g a.i./ha for chilli yellow mite with waiting period of 3 days.

Etoxazole

Etoxazole is a new generation insecticide and acaricide belongs to oxazoline class (Suzuki *et al.* 2001). Similar to hexythiazox, etoxazole has excellent efficacy on the eggs and nymphal stages of red spider mites, but ineffective against adult stages. The mechanism of action of etoxazole is inhibition of the moulting process or chitin biosynthesis during mite development (Nauen *et al.* 2006). Etoxazole is grouped in the subgroup 10B in IRAC mode of action classification. It is known as a biofriendly insecticide, an alternative to carbamates, organochlorines, and other acaricides and insecticides. However, the ecotoxicological properties of etoxazole are not much favorable as compared to hexythiazox. It is available mainly as 10 % SC and recommended dose for red spider mite is 40 g a.i./ha in brinjal (Karmakar and Sandip, 2013) with waiting period of 5 days

Flufenzine (Diflovidazin) / Flumite

Flufenzin is a selective acaricide with a broad spectrum against spider mite species like *Tetranychus* spp., *Panonychus* spp., and eriophyid mites. Highly efficient against mixed mite populations of different species and life stages. Flufenzine is a unique acaricide which inhibits the growth of mites (Kodandaram *et al.* 2013) It very effective against egg stage of chilli mite, *Polyphagotarsonemus latus* (Sarkar *et al.* 2014) and also destroys all the motile larval and chrysalis forms of *T. urticae*. Flufenzin has both translaminar and transovarial activity but also effective through vapor phase and destroys the larvae feeding on the lower surface of the leaf. The IRAC group code is 10A. Foliar application of flumite has long lasting effect for 40-60 days. Flufenzin 20 SC @ 100 g a.i./ ha was found effective against red spider mite, *Tetranychus cinnabarinus* on brinjal (Naik *et al.* 2006). It has very favorable ecotoxicological properties and found safe for predatory insects, parasitic wasps, pollinating bees, predatory mites and harmless to fishes. The unique properties of flufenzine make it fit under integrated pest management (IPM) systems. The field application rates is 80-100 g a.i./ha and vary with different crops.

Cyflumetofen

Cyflumetofen is a recently developed pro-acaricide which needs bio-activation by hydrolysis and belongs to beta-ketonitrile compounds with novel mechanism of action (Sparks *et al.* 2011). Cyflumetofen has good contact action and provides rapid knockdown of all life stages of spider mites species, within 3 hours after application. However, some multi-resistant strains of *T. urticae* may show cross-resistance (Khalighi *et al.* 2014). It interferes with mitochondrial electron transport and inhibits complex II of mitochondrial electron transport chain (Hayashi *et al.* 2013). The IRAC group code is 25 A. It dose not not affects non-targeted arthropod species (Gotoh *et al.* 2011) and can be integrated in IPM programs. It is available as 20% SC and the recommended dose is 125-150 g a.i/ha.

Tolfenpyrad

Tolfenpyrad is abroad spectrum foliar contact insecticide used in wide range of crops against several economically important insect pests of order hemiptera, thysanoptera, eriophid and tarsonemid mites (Anonymous, 1996). It has activity on all developmental stages of target insect. It works by inhibiting the cellular respiration in mitochondria, as a result, the compound causes rapid cessation of feeding and death of pests within 24-48 hours of treatment. The IRAC group code is 21A. Tolfenpyrad is available as 15 % EC formulation and recommended against sucking pests in okra (Bajpai and Singh, 2010; Bajpai and Jeengar, 2014).

Bifenazate

Bifenazate is an excellent acaricide found effective against all stages of spider mites species in open and greenhouse vegetables crops (Ochiai *et al.* 2007). It has good contact and stomach action wih quick knockdown effect and has long residual control. Bifenazate is a pro-acaricide (Van Leeuwen *et al.* 2006) that acts on Mitocondrial electron transport complex III (Van Nieuwenhuyse *et al.* 2012). The IRAC group code is 20 D. Mites sprayed with bifenazate becomes hyperactive after 3 hours and will no longer feed. Bifenazate demonstrates highly favorable ecobiological profile at the same time highly selective towards pollinating insects or beneficial predatory mites or wasps with no adverse effects (Ochiai *et al.* 2007; Kim and Seo, 2002). Bifenazate is available as 50 % WP and 22.6 % SC with recommended dose of 375 and 120 g a.i./ha, respectively.

Insecticide Mixtures or Combination Products

The mixtures of two or more insecticides are used in agriculture for various reasons. Combination products are usually applied in the field to increase the spectrum of the pest control when multiple pests are attacking simultaneously. The premix formulations may give better control of a complex of pests whose susceptibilities to active ingredients of the mixtures differ. Use of mixtures can aid in better management of pests that are resistant to individual toxicants, synerzise the efficacy of each active ingredients and consequently reduce the input cost and give economical control of target insect pest (Wolfenbarger and Cantu, 1975; Martin *et al.* 2003; Attique *et al*, 2006). Theoretically, insecticide mixtures are known to delay the onset of resistance development more effectively than rotation of insecticides if resistance to each compound is independent and rare (Curtis, 1985). Use of insecticide mixtures or combination products as a counter measure for resistance management aganist insect pests has been advocated by several researchers like Ishaaya *et al.* 1985; Ascher *et al.* 1986; Mushtaq, 2004. The multipurpose uses of these combination products clearly suggest that they are likely to become indispensable part of pest control strategy in future. The approved formulation of combination products available for pest control in vegetable crops is mentioned in table 3.

Maximum Residue Limits (MRL)

Maximum Residue Limits are the safe limits where maximum level of pesticide is expected on a food commodity after its safe use (Dureja *et al.* 2015). These are higher legal levels of a concentration for pesticide residues in or on food based upon good agricultural practices (GAP) and to ensure the lowest possible consumer exposure. The MRL values are fixed to ensure that the total amount of pesticide residues absorbed through food consumption will not exceed the acceptable daily intake (ADI) for a pesticide, whichever it may be. Apart from these, MRL also serve as monitoring tools. However, not all the foods containing pesticides above MRL are unsafe as long as any calculated acute reference dose has not been exceeded. MRLs are fixed low enough to make sure that the consumers will not consume more than the Acceptable Daily Intake (ADI). The Codex Alimentarius Commission of the FAO/WHO fixes the MRL values at the international level. The Codex Committee on Pesticide Residues (CCPR) was esatblished by the United Nations with a primary mandate to fix the MRL for pesticides in food.

In India, the MRL values of different pesticide commodity or combinations are prescribed under the Food Safety and Standards Regulations, 2010 Act (Table 4). This Act authorizes the Food Safety and Standards

Table 2. Novel insecticides and acaricides for control of sucking pests and their label claim in vegetable crops

	Common Name	Strength (%) and Formulation	Target Crop	Target Pests	Dosage /Ha			Waiting Period (days)
					a.i (gm)	Formulation (gm/ml)	Dilution in water (Litre)	
1.	Acetamiprid	20 SC	Cabbage	Aphids	15	75	500-600	7
			Okra	Aphids	15	75	500-600	3
			Chilli	Thrips	10-20	50-100	500-600	3
2.	Buprofezin	25 SC	Chillies	Yellow Mite	75-150	300-600	500-750	5
		70 DF	Okra	Jassids	200	286	500	5
3.	Chlorfenpyre	10 SC	Chilli	Yellow Mite	75-100	750-1000	500	5
4.	Cyantraniliprole	10.26 OD	Cabbage	Aphid	60	600	500	5
			Chilli	Thrips	60	600	500	5
			Tomato	Aphids, Thrips, Whitefly	90	900	500	3
			Gherkins	Aphid And Thrips	90	900	500	5
			Brinjal*	Shoot and fruit borer and whitefly	90-105	900-1005	500	-
			Okra*	Whitefly	90	900	500	1
5.	Difenthiuron	50 WP	Chilli	Mites	300	600	500-750	3
			Brinjal	Whitefly	300	600	500-750	3
6.	Emamectin Benzoate	5 SG	Chilli	Thrips, Mite	10	200	500	3
7.	Etoxazole	10 SC	Brinjal	Red Spider Mite	40	400	400-500	5
8.	Fenazaquin	10 EC	Chilli	Yellow Mite	125	1250	400-600	10
			Okra	Red Spider Mite	125	1250	500	7
			Brinal	Red Spider Mite	125	1250	500	7
			Tomato	Two Spotted Spider Mite	125	1250	500	7
9.	Fenpropathrin	30 EC	Chilli	Thrips, Whitefly, Mites	75-100	250-340	750-1000	7
			Brinjal	Whitefly, Mites	75-100	250-340	750-1000	10
			Okra	Whitefly, Mites	75-100	250-340	750-1000	7
10.	Fenpyroximate	5 EC	Chilli	Yellow Mite	15-30	300-600	300-500	7
11.	Fipronil	5 SC	Chilli	Thrips, Aphids	40-50	800-1000	500	7
12.	Flonicamid	50 WG	Okra*	Whitefly, Leafhopper	75	150	500	16
13.	Flumite/ Flufenzine	20 SC	Brinjal	Mites	80-100	400-500	500-1000	5
14.	Flupyradifurone	200 SL	Okra*	Whitefly, Leafhopper	250	1000-1250	500	-
15.	Hexythiaox	5.45 EC	Chilli	Yellow Mite	15-25	300-500	625	3
16.	Imidacloprid	70 WG	Okra	Jassids, Aphids, Thrips	21-24.5	30-35	375-500	3
			Cucumber	Jassids, Aphids	24.5	35	500	5
		48 FS	Okra	Jassids, Aphids	300-540 (per 100 kg seed)	500-900		
		70 WS	Okra	Jassids, Aphids	350-700 (per 100 kg seed)	500-1000		
			Chilli	Jassids, Aphids, Thrips	700-1050 (per 100 kg seed)	500-1000		
		17.8 SL	Chilli	Jassid, Aphid, Thrips	25-20	125-250	500-700	40
			Okra	Jassid, Aphid, Thrips	20	100	500	3
			Tomato	Whitefly	30-35	150-175	500	3
17.	Milibectin	1 EC	Chilli	Mites	3.25	325	500	7
18.	Propergite	57 EC	Chilli	Mite	850	1500	500-625	7
			Brinjal	Two Spotted Spider Mite	570	1000	400	6
19.	Pyriproxyfen	10 EC	Chilli	White Fly, Aphids	50	500	300	7
20.	Spinetoram	11.7 SC	Chilli	Thrips	56-60	470-500	400-500	7
21.	Spinosad	45 SC	Chillies	Thrips	73	160	500	3
22.	Spiromesifen	22.9 SC	Brinjal	Red Spider Mite	96	400	500	5
			Chilli	Yellow Mite	96	400	500-750	7
			Okra	Red Spider Mite	96-120	400-500	500	3
			Tomato	Whiteflies, Mites	150	625	500	3
23.	Spirotetramate	150 OD	Okra * Brinjal*	Whitefly	90	600	500	-
24.	Thiacloprid	21.7 SC	Chilli	Thrips	54-72	225-300	500	5
25.	Thiamethoxam	30 FS	Cotton	Aphid,Whitefly, Jassids	3	10		
			Chilli	Thrips	2.1	7		
			Okra	Jassids	1.7	5.7		
		25 WG	Okra	Jassid, Aphid, Whitefly	25	100	500-1000	5
			Tomato	Whitefly	50	200	500	5
			Brinjal	Whitefly	50	200	500	3
		70 WDG	Okra	Aphids	200	286		
			Tomato	Aphids, Thrips	420	600		
26.	Tolfenpyrad	15 EC	Cabbage	Aphids	150	1000	500	5
			Okra	Aphids, Jassids, Thrips, Whitefly	150	1000	500	3

(Source: Kodandaram *et al.* 2010, 2013 and http://www.cibrc.nic.in); *IIVR Recommendation

Table 3. Combination products approved for control of sucking pests and their label claim in vegetable crops

	Common Name	Strength & Formulation	Crop	Target Pests	Dosage /Ha			Waiting Period (days)
					a.i (gm)	Formulation (gm/ml)	Dilution in water(Litre)	
1.	Betacyfluthrin Imidacloprid	+ 8.49% + 19.81% OD	Brinjal	Aphids, Jassids	15.75+36.75 to 18 + 42	175-200	500	7
2.	Cypermethrin Quinalphos	+ 3% + 20% EC	Brinjal	Shoot & Fruit borer	-	350-400	500-600	7
3.	Deltamethrin Trizophos	+ 1% + 35% EC	Brinjal	Fruit, Borer, Jassids, Aphid, Hadda beetle	10+350-12.5+450	1000-1250	500	3
4.	Flubendiamide Thiacloprid	+ 19.92% +19.92%	Chilli	Thrips Fruit borer	48+48-60+60	200-250	500	5
5.	Indoxacarb Acetamiprid	+ 14.5 %+7.7 % SC	Chillies	Thrips, & Fruit borer	88.8-111	400-500	500	5
6.	Novaluron Indoxacarb	+ 5.25% + 4.5% SC	Tomato	Fruit borer & leaf eating caterpillar	43.31+ 37.13 to 45.94 + 39.38	825-875	500	5
7.	Pyriproxyfen Fenpropathrin	+ 5% +15% EC	Brinjal Okra Chilli	Whitefly Fruit borer	25+75 to 37.5 +112.5	500-750	500-750	7
8.	Thiamethoxam +Lambda cyhalothrin	12.6%+9.5% ZC	Chilli	Thrips and Fruit borers	33	150	500	3
9.	Chlorantranili prole Thiamethoxam	+ 8.8% +17.5 % SC	Tomato	Leaf Miner, Whitefly & Fruit borer	150	500	As Soil drench (Single application) 50-100 ml/ plant. 8-10 days DAT	36

(Source: Kodandaram et al., 2013 and and http://www.cibrc.nic.in)

Table 4. The MRL values of insecticides and acaricides used for pest control in vegetable crops

Sl. No.	Insecticides	MRL or Tolerance Limits in mg/kg (ppm)						
		Tomato	Brinjal	Chilli	Okra	Cabbage	Cauliflower	Cucurbits
1.	Acetamiprid	-	--	0.1**	0.1**	0.1**	-	-
2.	Buprofezin	-	-	0.01**	0.01*	-	-	-
3.	Chlorantranilprole	-	-	-	-	0.03**	-	-
4.	Chlorfenpyre	-	-	0.05**	-	0.05**	-	-
5.	Difenthiuron	-	1.0**	0.05**	-	1.0**	-	-
6.	Emamectin benzoate	0.02*	0.02*	0.02*	0.05**	0.02*	0.02*	0.03*
7.	Etoxazole	-	-	-	-	-	-	0.02*
8.	Fenazaquin	-	-	0.5**	-	-	-	-
9.	Fenpropathrin	-	0.2**	0.2**	0.5**	-	-	-
10.	Fenpyroximate	-	-	1.0**	-	0.2*	0.2*	-
11.	Fipronil	-	-	0.001**	-	0.001**	-	-
12.	Flumite/ Flufenzine	-	0.5**	-	-	-	-	-
13.	Flupyradifurone	3.0*	3.0*					1.5*
14.	Hexythiazox	0.1*	0.1*	0.01**	-	-	-	0.02*
15.	Lufenuron	-	-	-	-	0.3**	0.1**	-
16.	Milibectin	-	-	0.01**	-	-	-	-
17.	Propargite	-	-	2.0**	-	-	-	-
18.	Pyridalyl	-	-	0.2**	0.02**	0.02**	-	-
19.	Spinosad 2.5 SC	-	-	-	0.02**	0.02**	-	-
20.	Spinosad 45 SC			0.001**	-	-	-	
21.	Spiromesifen	0.3**		-	-	0.02**	-	-
22.	Spirotetramat						1.00*	
23.	Sulfoxaflor						0.04*	0.5*
24.	Thiacloprid			0.02**	-	-	-	-
25.	Thiodicarb			0.01**	-	-	-	-
26.	Thiamethoxam	0.01**	0.3**	0.01**	0.5**	-	-	-
27.	Tolfenpyrad			-	0.7 **	0.01**	-	-

(Source: Kodandaram *et al.* 2013 and http://www.fssai.gov.in) ** FSSAI MRL values, * Codex MRL values

Authority of India (FSSAI) to specify and fix the limits for use of all food additives like crop contaminants, pesticide residues, residues of veterinary drugs, heavy metals, processing aids, mycotoxins, antibiotics and pharmacologically active substances and irradiation of food.

Pre Harvest Interval (PHI) / Waiting Period

PHI is the shortest period of time which must be left between pesticide application and crop harvest in order to ensure that residues do not exceed the MRL. Pre harvest interval (PHI) or waiting period of insecticides should be considered in chemical control of insect pests. As a thumb rule, to minimize residue accumulations, the insecticides with less PHI should be given preference against the longer persistent alternatives. In the plant protection schedule also, the applications of pesticides are required to be staggered as per their relative PHIs so that the initial residue deposits dissipate to below the MRLs at the stage of harvest. Generally, establishing a PHI for a pesticide involves multi-location field trials wherein the pesticides are applied following the guidelines of good agricultural practices (GAP). Samples are collected from the treated plants and analyzed for the residues. The collection of sample starts from the day of the final spraying and continued at regular intervals till harvest.

The residues in each sample is estimated and the residue data are statistically processed to correlate the dissipation with progress of time.

Conclusion

Many of the above mentioned newer insecticides and acaricides have several advantages over conventional ones like high level of selectivity to target insect pests, excellent efficacy at lower field rates, non-persistent in the environment, low mammalian toxicity, cause less harm to natural enemies, less likely to cause outbreaks of secondary pests, helpful for delaying insecticide resistance and have no cross-resistance with the conventional insecticides. Therefore, these molecules with green chemistry are going to remain as a critical components of most of the Integrated Pest Management (IPM) and resistance management programs. However, at the same time, there is a real need and responsibility of the growers to use them judiciously at recommended dosage to avoid any loss in the efficacy of these new chemistries in future and sustain their use for longer period in vegetable pest control.

सारांश

भारतवर्ष की जनसंख्या वृद्धि के अनुरूप भविष्य में सब्जी उपज की मांग को पूरा करने में कई चुनौतियाँ है। सब्जी की खेती करने में चूसक कीटों का प्रकोप प्रमुख समस्या है जिससे ज्यादा नुकसान होता है। कई चूसक कीट जैसे– वहाइट फ्लाई, थ्रिप्स, एफीड्स, मिलीबग एवं मकड़ी केवल सीधे तौर पर चूसकर ही नुकसान नहीं पहुँचती बल्कि उनमें ज्यादातर अनेकों पौध रोगजनक विषाणु के वाहक हैं। पारंपरिक कीटनाशियों अथवा मकड़ी नाशकों का बड़े पैमाने पर उपयोग इन चूसक कीटों के नियंत्रण हेतु किया जा रहा है लेकिन इनमें ज्यादातर कम प्रभावकारिता, कई गुना प्रतिरोधिता विकास तथा कीट पुनरूथान के कारण असफल हैं। हरित रसायन युक्त आधुनिक कीटनाशियों अथवा मकड़ी नाशकों में उद्देश्य परक उत्कृष्ट जैव रसायन इन चूसक कीटों के प्रकोप के खतरों से लड़ने के लिये उपलब्ध हैं। आधुनिक यथा एकीकृत जीवनाशी प्रबंधन हेतु एक उपयुक्त घटक है जिन्हें सब्जियों में प्रतिरोधी प्रबंधन कार्यक्रम में सम्मिलित किया जा सकता है। यह अध्याय पिछले एक दशक से प्रचलित अभिनव उत्पादों का अवलोकन प्रस्तुत करता है तथा भविष्य में सब्जी कीटों के नियंत्रण की संभावनाओं पर प्रकाश डालता है।

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