The Insecticide and Miticide Mode of Action Field Guide[1]

A Resource to Assist in Managing Arthropod Pests of Turfgrass and Ornamental Plants

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The Insecticide and Miticide Mode of Action Field Guide (W 415) was developed as a companion to publication W 329 "An Ornamental Plant Pest Management Guide and Pesticide Rotation Planning Aid: Control options for Nursery, Greenhouse, Interiorscape and Commercial Landscape Use Sites" (extension.tennessee.edu/publications/Pages/default.aspx). W 415 describes the mode of action and discusses the function of insecticides and miticides that are available for use against arthropod pests infesting ornamental plants in nurseries, greenhouses, interiorscapes, landscapes and turfgrasses[1,2].

Development of Pesticide Resistance

Pesticide resistance reduces the effectiveness of a particular pesticide (insecticides, fungicides, herbicides and others) after repeated and typically long-term uses of the pesticide. Pesticide resistance arises from a reduction in the susceptibility of a pest population to a particular pesticide. This reduction in susceptibility is the product of two interacting factors — pesticide **Mode of Action (MOA)** and pest genetic plasticity.

Most insecticides and miticides (also called acaricides) affect one of the five essential biological processes or systems in arthropods: 1) the nervous system; 2) metabolic energy production; 3) growth; 4) physiological or structural function (including feeding and water balance); and 5) targeting midgut membrane integrity. After insecticide molecules enter the arthropod's body, either through the cuticle (contact poisons), through spiracles (fumigation), or by ingestion (stomach poisons), the molecules bind to specific enzymes or receptors in cells. Once bound, the insecticide molecules disrupt or alter neural, metabolic, developmental or other physiological functioning within the pest, eventually leading to the death of the treated pest.

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[1] Chemical subgroups presented within this document are based on **Insecticide Resistance Action Committee (IRAC)** classifications (http://www.irac-online.org/modes-of-action/)

[2] *Disclaimer:* The focus of this document is on insecticidal and miticidal active ingredients; many different brand names may be available within each group. Where brand names are given as examples, mention of that brand name or any active ingredient does not imply approval, endorsement or guarantee of the products. Use pesticides only according to the directions on the label. Follow all directions, precautions and restrictions that are listed.

Although insects (or mites) in a population look almost identical to each other, the individuals will differ slightly either by the genes they carry or how those genes may function. This genetic variation confers different abilities to alter physiological function in response, for example, to environmental or other stressors including toxins. Some individuals may carry "resistance" genes or possess genetic mutations that help them tolerate a given insecticide stressor. These individuals may be better able to modify slightly the structure of the enzymes or receptors targeted by the insecticide. In turn, these slight modifications can reduce or neutralize the ability of the pesticide molecules to bind to the receptor sites. In essence, these genetic mutations or resistance genes sustain normal and essential physiological functioning, thus enabling the pest to survive the toxic effects of the insecticide. When insecticide-resistant individuals reproduce, they can pass on the "resistance" genes to the next generation. If the same stress continues to affect the population across several generations, a greater proportion of susceptible individuals will die, yet more resistant individuals will survive and reproduce. In other words, long-term use of the same pesticide functions as a continuous selection factor that enables a population to become increasingly resistant to the pesticide. Operationally, a pest manager may observe reduced efficacy of the pesticide across time.

The risk of developing pesticide resistance is greater in pests that reproduce rapidly, such as aphids, mites, thrips and whiteflies that produce high numbers of offspring across multiple generations within a growing season. The risks of pesticide resistance are greater yet where these pests are contained within a monoculture crop or enclosed production system, like a greenhouse, where interbreeding with wild-type or susceptible individuals is restricted. Under these conditions, there is higher likelihood that a pesticide-resistant individual of one gender will find a pesticide-resistant mate.

Cross-resistance occurs when a single or a series of genetic mutations that confers resistance to one insecticide also provides resistance to another insecticide. Among ornamental plant pests, for example, a small population of western flower thrips (*Frankliniella occidentalis*) with resistance to imidacloprid can also demonstrate cross-resistance to acetamiprid to which it may not have been exposed. Both of these insecticides are neonicotinoids classified in Insecticide Resistance Action Committee's Mode of Action Group 4A (IRAC 4A). **Multiple resistance** can occur when a pest becomes resistant to more than one pesticide mode of action after prolonged and sequential exposure to multiple chemical classes. In an extreme example, a single diamondback moth strain (*Plutella xylostella* CH1) has developed cross-resistance to spinosyns (IRAC 5), abamectin (IRAC 6) and some *Bt* insecticides (IRAC 11).

Regardless, managing other populations of high resistance-risk species, including western flower thrips, may warrant additional efforts at pro-active pesticide rotation planning that features use of different pesticide modes of action. See Table 1 for a list of high resistance-risk pest species and guidelines on sustainable IRAC class selection.

Table 1. A list of high resistance-risk arthropod species and chemical classes for which cross-resistance or multiple resistance can occur.

Example pest species	**Pest management applications made from IRAC Group (a.i.):**	**Are best when *not preceded by/or followed by* products applied from IRAC Group (a.i.)**
Western flower thrips	1B (chlorpyrifos)	3A (cyhalothrin), 6 (abamectin)
Green peach aphid	4A	4C (sulfoxaflor), 4D (flupyradifurone)
Glasshouse & silverleaf whiteflies	4A (neonicotinoids)	9B (pymetrozine)
Panonychus spider mites	10A (clofentazine, hexathiazox), 10B (etoxazole)	15 (diflubenzuron, novaluron)
Twospotted spider mite	20D (bifenazate)	20B (acequinocyl)

Pest resistance to insecticides and acaricides is a real and growing concern. Efforts to limit pesticide resistance should be an active part of pest manager's decision-making portfolios. The "Arthropod Pesticide Resistance Database" is a searchable tool (pesticideresistance.com) that compiles and shares published evidence about species, conditions and geographic locations where pest resistance to pesticides has been documented. Select pest species, including spider mites, western flower thrips, sweetpotato whiteflies and green peach aphids that are all frequently encountered in ornamental plant production systems, are among the top 12 species that have developed resistance to multiple pesticide active ingredients spanning several chemical classes.

How Can You Avoid or Delay Pesticide Resistance?

A plant producer or pest manager can avoid or delay the development of pesticide resistance by following a few **Best Practice** guidelines:

1. Adopt an integrated pest management (IPM) approach when producing plants and managing established turfgrasses and ornamental plants:
    a. Strive to apply pesticides only when needed to limit aesthetic or economic losses;
    b. Select pesticides that complement cultural and biological control tactics; and
    c. Where available, use pest resistant and less-susceptible host plants;
2. Apply pesticides at the recommended rates, follow recommendations on the maximum amount applied or frequency of application per season, and achieve thorough coverage;

3. Target pests when they are at their most susceptible life stage;
4. Rotate among pesticides that provide different MOA and change to a different MOA for each pest generation;
5. If a tank mix is desired, choose pesticides with different MOA;
6. Use combination products that contain active ingredients of different MOA; and
7. Do not reapply with a pesticide of the same MOA when you perceive that pest susceptibility to that pesticide has become noticeably reduced.

Pesticide resistance can often be at least partially reversed. **Reversal** may occur in two ways. First, stop using the failed pesticide MOA for several generations. Most physiological modifications that confer pesticide resistance can be functionally costly to the resistant pest. These costs add up as a consequence of reduced metabolic efficiency, an increase in energy expenditures for survival, and as a reduction in reproduction or fitness. Once the stressor (i.e., the pesticide) is removed, the lower performing but resistant individuals may be gradually outcompeted by higher performing but less resistant individuals. The second way reversal may occur is through migration of susceptible individuals from another population and the dilution of resistant individuals. This reversal mechanism may occur in an open environment where wild-type, susceptible individuals can enter to reproduce. As the susceptible and resistant individuals mate, the resistant genes are further diluted.

Understanding Mode of Action and the IRAC Classification Scheme

Exploiting physiological **Modes of Action (MOA)** to assist in managing pest organisms provides the conceptual foundation for a pesticide resistance management program. Pesticide resistance often arises from repeated use of a single mode of action. A practical solution to avoiding pest resistance is to use pesticides with different modes of action to manage each pest generation. In other words, to practice pesticide rotation.

Insecticides and miticides are grouped into various **chemical classes** (sometimes called chemical groups or chemical families) according to their chemical similarities. For example, acephate, chlorpyrifos and trichlorfon are all members of the organophosphate chemical group because these compounds are very similar chemically, molecularly and functionally. Often, several chemical classes share the same mode of action because they kill insects and mites through the same biochemical processes or pathways.

To facilitate the design of an appropriate pesticide rotation program, the **Insecticide Resistance Action Committee (IRAC)** classifies all manufactured insecticidal and acaricidal chemicals according to their modes of action. Each mode of action is categorized with a unique group number and chemical class within a single MOA group may receive a unique number-letter combination (see W 329, extension.tennessee.edu/publications/Pages/default.aspx). For example, carbamates are classified as 1A, whereas organophosphates are classified as 1B. The same number (“1”) indicates that carbamates and organophosphates are of the same mode of action (acetycholinesterase inhibitors) but the different letters (“A” vs. “B”) indicate that they are of different chemical classes. A pest manager who uses acephate (an organophosphate, 1B) against a pest population should rotate to a product of different mode of action (e.g., dinotefuran, a neonicotinoid, or other 4A chemical),

against the next generation, not to one of the same mode of action (e.g., carbaryl, a carbamate, or other 1A chemical).

Most pesticide manufacturers prominently display the IRAC MOA group number on their product labels. Many newer products do include such labeling and our section headings reflect this convention. The inclusion of IRAC MOA group number is extremely helpful in clearly informing the pest managers and applicators about the mode of action of the product and assisting them in selecting appropriate pesticides in accordance to pesticide resistance management guidelines.

How Can Knowing About Mode of Action Improve Your Likelihood of Successful Pest Management?

A better understanding about how insecticides or miticides kill their target pests is important in selecting the most efficacious chemicals to manage the target pest. The best pest managers share a fundamental understanding about pesticide modes of action. This knowledge helps the pest manager to develop a pesticide rotation program that will help prevent or delay the development of pesticide resistance in the target pest populations.

Notes on Pollinator Conservation

Concerns raised about the safety of neonicotinoid insecticides to pollinating insects interacting with treated plants has increased dialogue and research about the status and health of pollinators including honey bees, bumble bees and native bee species in the US. Pesticide applicators are expected and legally required to read and follow the application restrictions listed on the label. In general, it is prudent practice to take steps that reduce exposure of pollinators to pesticides, and especially insecticides, including:

- Not applying neonicotinoids and broad spectrum insecticides to flowering plants if the plants are known to be attractive to foraging pollinators, or if pollinators are observed to be foraging on the plants.
- Minimizing direct exposure to foraging pollinators to applied pesticides.
- Minimizing pesticide spray drift to beehives and onto pollinator-attractive plants.

The Horticultural Research Institute has released Best Management Practices (BMPs) for Bee Health in the Horticultural Industry, which includes guidelines for protecting pollinators in ornamental plant and turfgrass systems: growwise.org/wp-content/uploads/2017/01/HRI-Pollinator-BMPs-January2017.pdf.

Another good resource is Protecting and Enhancing Pollinators in Urban Landscapes that, although developed for the US North Central Region, provides practical information that is broadly applicable in the eastern US. The resource is available as MSU Extension Bulletin E3314: msue.anr.msu.edu/uploads/236/78920/ProtectPollinatorsInLandscape_FINAL-HigherRes.pdf.

Other links to related resources will be added as they become available. Also check for updates to the Pollinator Stewardship Project, available at the Horticultural Research Institute (HRI) Initiatives website (hriresearch.org/HRI/Research/Special_Initiatives.aspx).

GROUP 1 INSECTICIDE

GROUP MODE OF ACTION

Acetylcholinesterase inhibitors

IRAC CHEMICAL SUBGROUPS[1]

Carbamates (1A); Organophosphates (1B)

General Group Profile

Broad spectrum, contact insecticides and miticides; quick knockdown; some active ingredients (e.g., acephate, dicrotophos, oxydemeton methyl) may have moderate systemic activity and translocation within plant tissues.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(1A) carbaryl, methiocarb; (1B) acephate, chlorpyrifos, dicrotophos, dimethoate, malathion, oxydemeton methyl, trichlorfan

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How the Chemistry Works Within the Pest

Carbamates and organophosphates are nerve poisons that work by disrupting the normal transmission of nerve impulses and signals. When functioning properly, nerve impulses cross the synaptic gap between nerve cells by way of a neurotransmitter called acetylcholine. When an electrical nerve signal arrives at the end of a nerve cell, the nerve cell releases acetylcholine molecules, which travel across the synaptic gap and bind with receptors on the next nerve cell, triggering the generation of electrical nerve signal that then travels the length of the next nerve cell. Once the signal is transmitted, acetylcholinesterase (an enzyme) degrades acetylcholine molecules so that nerve signals are no longer fired. Carbamates and organophosphates inhibit the action of acetylcholinesterase. As a result, the acetylcholine molecules accumulate and continue to stimulate receptors into generating nervous impulses.

How You Might Observe that Treatments are Working

Typical symptoms of continuous nerve stimulation are apparent in treated insects, which display hyperactivity and rapid twitching of voluntary muscles. Eventually, overstimulation will lead to respiratory failure, paralysis and then death.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Wide pest range that includes caterpillars, beetles, sawflies, leafminer and some mites, with good efficacy against sucking insects (like scale insects, aphids and lace bugs),

Notes on Interactions With Non-Target Arthropods

Carbamates and organophosphates have high acute toxicity (thus a quick knockdown of both pests and non-target arthropods, and are also highly toxic to mammals). Products have varying durations of persistence in the environment. For example, malathion has a half-life (i.e., the amount of time needed to break down 50 percent of the compound in the environment) of 2-17 days in water and 1-17 days in the soil, whereas the half-life of diazinon is 12 hours (in high acidity) to 6 months (in neutral pH) in water and 2-4 weeks in the soil. The long persistence of pesticides in the soil and water means that a concentration lethal to the non-target organisms may be present within the period of persistence, thus posing significant risks to non-target organisms in those environments.

Origin and History

Carbaryl was the first carbamate introduced in 1956. Organophosphate insecticides were derived from products of nerve gas research during World War II. Malathion, which was introduced in 1950, is among the oldest organophosphates still in use.

Current Status

Being some of the oldest pesticides, there are a large number of carbamates and organophosphates still in use in the green industry. Carbaryl, acephate, malathion and trichlorfon are still some of the most commonly used chemicals. Non-agricultural uses of others in landscape settings either require specialized equipment or injection technologies (dicrotophos, methidathion and oxidemeton methyl), or have been greatly restricted (e.g., chlorpyrifos, dimethoate and methiocarb) or cancelled (e.g., diazinon) by US EPA in recent years following concerns related to acute mammalian toxicity and environmental risks from these compounds. The trend in phasing-out the carbamates and organophosphates will likely continue.

GROUP 2 INSECTICIDE

GROUP MODE OF ACTION

Gamma-aminobutyric acid (GABA)-gated chlorine channel antagonists

IRAC CHEMICAL SUBGROUPS[1]

Phenylpyrazoles (2B)

General Group Profile

Chemicals in this group are primarily stomach poisons (only limited dermal exposure) and act very slowly. The slow action of fipronil allows this chemical to be formulated as baits for many structural pests; the slow action allows the foraging individuals to survive for some time and carry the baits back to the colony. Fipronil also appear to have repellency against some common turfgrass insect pests.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(2B) fipronil

How the Chemistry Works Within the Pest

When functioning normally, gamma-aminobutyric acid (GABA) binds to postsynaptic receptor proteins at the end of nerve cells and enables chlorine channels to open, allowing chlorine ions flow into the nerve cell and dampen nerve impulses. On application, Group 2 insecticides bind to GABA receptors, leading to continuous closure of chlorine channels. Synaptic responses are inhibited, eventually causing the nervous system to become paralyzed.

How You Might Observe that Treatments are Working

Insects become hyper-excited and die.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

In the green industry, fipronil is used as an effective, long-lasting management tool against red imported fire ant, nuisance ants, mole crickets, fleas and ticks.

Interactions with Non-Target Arthropods

Fipronil also has high environmental risks and must be used carefully. Fipronil is highly toxic to fish, aquatic invertebrates, bees and other pollinators.

Additional Notes for Optimal Deployment

For best results, fipronil granules should be wetted and dissolved (by rainfall or irrigation) shortly after application to facilitate formation of a protective layer on the soil surface. Subsequent soil disruption (e.g., tillage or aerification) in treated areas should be minimized to avoid disrupting the protective layer.

Origin and History

Fipronil was discovered in 1987 and commercialized in 1993. This is now the only insecticide in this group that is still been used in the green industry, primarily on the turfgrass. Fipronil is also used extensively in structural (e.g., against termites) and veterinary pest management (e.g., monthly flea and tick treatment for pets).

Current Status

Endosulfan (Endosulfan, Thiodan) is a cyclodiene organochlorine (2A) developed in 1956. In the past, endosulfan was used extensively in the turf and ornamental industry for aphid, whitefly, borer and mite management. Endosulfan is now banned in the US because of its acute neurotoxicity to human and other mammals. In some references, DDT was considered a member of the organochlorine chemical class (2A). However, the most current IRAC grouping places DDT as a chemical class within Group 3. Fipronil is a phenylpyrazole (2B) that is the only commercially available product in this group labeled for commercial nursery or professional landscape management. EPA has put stringent restrictions on use site and requirements for a buffer zone to minimize negative impacts of fipronil on aquatic invertebrates.

GROUP 3 INSECTICIDE

GROUP MODE OF ACTION

Sodium channel modulators

IRAC CHEMICAL SUBGROUPS[1]

Pyrethrins, Pyrethroids (3A)

General Group Profile

Pyrethroids have a broad spectrum of contact toxicity and quick knockdown. Pyrethroids also have strong repellency, making them excellent candidates for preventive management of certain insects. They are also stable in water, soil and under sunlight.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(3A) bifenthrin, beta-cyfluthrin, cyfluthrin, lambda-cyhalothrin, cypermethrin, deltamethrin, fenpropathin, tau-fluvalinate, permethrin, pyrethrins

How the Chemistry Works Within the Pest

Pyrethroids, methoxychlor interfere with the normal function of the nervous system by disrupting sodium/potassium ion equilibrium along nerve cell membranes. Pyrethroids hold sodium channels open and allow more sodium ions to flow into the nerve cell, which causes excessive excitation.

How You Might Observe that Treatments are Working

Hyper-stimulated nerve cells repeatedly send nerve impulses. Affected arthropods may twitch after initial knockdown, then muscles become paralyzed causing energy depletion and death.

General Notes on Target Arthropods

Pyrethroids have broad-spectrum activities against sucking (e.g., aphids, whiteflies, mealybugs, plant bugs, thrips, etc.) and chewing insects (e.g., beetles and caterpillars). Pyrethroids can also be used as effective preventive sprays against wood boring insects and leafminers. Although labeled, the efficacy of pyrethroids against mites is typically mediocre.

Interactions with Non-Target Arthropods

Pyrethroids are broad-spectrum insecticides and therefore have significant detrimental effects on the survival of non-target arthropods, such as predatory insects, parasitoids, pollinators and soil decomposers. The disruption of natural biological control by pyrethroids may result in increased infestation and outbreaks of certain pests, like scale insects. Because of their high toxicity, pyrethroids should never be applied when pollinators are foraging.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

Additional Notes for Optimal Deployment

Pyrethroids are contact insecticides; therefore, thorough coverage of the plants should be achieved for maximum efficacy. The applications of pyrethroids are not effective against concealed pests, such as larvae of wood boring insects and leafminers; therefore, thorough topical applications on the trunks or leaves to prevent the entry of these insects (adults or larvae) are crucial to successful control.

Origin and History

Pyrethrins are natural organic compounds extracted from pyrethrum plants (*Chrysanthemum cinerariaefolium* and *C. coccineum*) that have been used since 400 B.C. The first synthetic pyrethroid, allethrin, was developed by the USDA in 1949 as modified chemical forms of naturally-occurring pyrethrum. To date, as many as 45 pyrethroids have been developed. Of these, nine are frequently deployed by the turf and ornamental industry for both professional and homeowner uses in managing pest arthropods. Dichlorodiphenyltrichloroethane, or DDT (3B) is another sodium channel modulating insecticide that was discovered in 1873. Although formerly considered a organochlorine (Group 2), current IRAC grouping places this chemical in Group 3. DDT is widely used during and after World War II and hailed as a significant contributor to improving human health. However, DDT also gains considerable notoriety for its long-lasting deleterious environmental impacts. In the US, registered uses of DDT (and methoxyachlor, another 3B insecticide) were cancelled and DDT was banned in 1973.

Current Status

Pyrethroids are the workhorses of the green industry. Hundreds of products and formulations containing bifenthrin, cyfluthrin, cyhalothrin, cypermethrin, deltamethrin, fenpropathin, tau-fluvalinate, permethrin and pyrethrins are currently available. Due to extensive use of this chemical class, pyrethroid resistance has been reported in many insect species, including many flies, mosquitos, leafminers, southern chinch bug and bluegrass weevil. To delay development of resistance and to prolong the effectiveness of pyrethroids, an active resistance management program should be employed.

GROUP 4 INSECTICIDE

GROUP MODE OF ACTION

Nicotinic acetylcholine receptor disruptors

IRAC CHEMICAL SUBGROUPS[1]

Neonicotinoids (4A); Nicotine (4B); Sulfoxaflor (4C); (4D) Flupyradifurone

General Group Profile

Neonicotinoids are systemic and may have high water solubility or less likelihood of binding to lipids. Compounds are absorbed by plant roots, leaves and stem or trunk tissues, and then transported to the branches and leaves via the plant vascular system. The speed at which the active ingredient is absorbed is the fastest in dinotefuran, followed by thiamethoxam, acetamiprid, imidacloprid and clothianidin. Insects then ingest neonicotinoids in plant sap and die. Sulfoxaflor is also a systemic compound, however, its speed of translocation is much slower than the neonicotinoids. Sulfoxaflor is typically tightly bound to organic matters in the soil or potting medium, making it unavailable for absorption; therefore, soil drench application of sulfoxaflor is not allowed on the label. Nicotine is a botanical extract, acetamiprid is a pyridylmethylamine neonicotinoid, while clothianidin, dinotefuran, imidacloprid and thiamethoxam are nitroguanidine neonicotinoids, and sulfoxaflor is a sulfoximine compound, and flupyradifurone is a butenolide compound.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(4A) acetamiprid, clothianidin, dinotefuran, imidacloprid, thismethoxam; (4B) nicotine; (4C) sulfoxaflor; (4D) flupyradifurone

How the Chemistry Works Within the Pest

Neonicotinoids, nicotine and sulfoxaflor, and flupyradifurone are acetylcholine mimics that permanently bind to nicotinic acetylcholine receptors effectively blocking nerve transmission. These compounds are insensitive to degradation by acetylcholinesterase, so nerve impulses are transmitted rapidly and uncontrollably. As chlorinated analogs of nicotine, neonicotinoids are much less toxic to mammals than nicotine.

How You Might Observe that Treatments are Working

Persistent activation of the nervous system leads to hyper-excitation, convulsions, paralysis and eventually death of treated insects. To determine the viability of scale insects, flip them over and examine the color of the bodies — if they are brown or black and desiccated, the insects are dead.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Systemic insecticides are often used to control sucking insects that feed on the phloem, including aphids, whiteflies, scale insects and mealybugs that feed in hard-to-reach places or have thick waxy deposits or shells that hinder the penetration of insecticide solutions. Neonicotinoids also have activity against beetles, caterpillars and thrips that are feeding on the foliage (see labels for specific groups or species). Sulfoxaflor is currently labeled for uses against sucking insects (aphids, whiteflies, mealybugs, plant bugs, some scale insects, thrips) and spider mites, shore flies, gall midges, and leaf-feeding beetles, sawflies and caterpillars. Fluryradifurone is currently labeled for uses against sucking insects, including aphids, leafhopper, lace bugs, mealybugs, psyllids, whiteflies, and soft and armored scales.

Interactions with Non-Target Arthropods

Nicotine and nicotine sulfate have serious environmental and health risks due to low efficacy against insects and high toxicity to mammals. About 60 mg (or 2/1000 oz) of pure nicotine is lethal to an average adult human. Because of the high mammalian toxicity, nicotine products are not registered for use as organic insect control solutions. Neonicotinoid insecticides can have detrimental effects on the survival and functions of beneficial insects and pollinators, including honey bees, particularly when applied to foliage. Based on honey bee acute LD_{50}, acetamiprid likely has lower toxicity to honey bees than clothianidin, dinotefuran, imidacloprid and thiamethoxam. Additional studies on the effects of flupyradifurone and sulfoxaflor on non-target organisms are being conducted.

Additional Notes about Neonicotinoid Interaction(s) with Pollinators

Neonicotinoids differ significantly among the active ingredients in their water solubility and mobility. Plant tissues translocate dinotefuran more readily than clothianidin, imidacloprid and thiamethoxam, allowing faster activity against target pests in tree canopy by dinotefuran. Acetamiprid, which binds tightly to soil, is not registered for soil drench, soil injection or granular application. New application methods, such as granular formulations, directed sprays to lower trunk sections, pellets and soil injection methods, have been developed for some neonicotinoid products. Recent studies suggested that the choice of application method does not influence the efficacy of the neonicotinoids. The duration of efficacy can be lenghtened considerably via root or bark uptake. The efficacy is also influenced by type of scale insect, feeding locations and life stages. Neonicotinoids generally do not have high efficacy against armored scales, adult female scales and those species that feed on the woody tissues.

Notes on Pollination Conservation When Using Neonicotinoid Insecticides

Neonicotinoids, when applied as foliar applications, can have detrimental effects on the survival and functions of beneficial insects and pollinators, including honey bees, bumble bees and native (solitary) bees. Sublethal and other effects may occur in response to systemic uptake by roots or bark. Neonicotinoid labels include prominent bee advisory box, which provides a clearly statement about potential impacts of the insecticide to bees and other pollinators, and direct the applicators to read the application restrictions listed on the label.

Origin and History

Water extracts of tobacco containing nicotine have been used for garden insect control as early as 1690. Discovery and research on neonicotinoids began in the 1970s. Imidacloprid was discovered in 1985 and commercialized in 1994. Acetamiprid, clothianidin, dinotefuran and thiamethoxam neonicotinoids were introduced to the turf and ornamental industry after 2000. Although the chemical group in which sulfoxaflor belongs is known to the chemists in 1940s, research for insecticidal properties of this compound did not begin until late 2000s. Dow AgroSciences introduced sulfoxaflor (in a combination product with spinetoram) to the ornamental market in 2014. Flupyradifurone was discovered in the late 1990s, following modifications to the chemical structure of stemofeline, an insecticidal natural compound extracted from the leaves and stems of oriental medicinal plant, *Stemona japonica*. Flupyradifurone was introduced to the ornamental market by Bayer in early 2017.

Current Status

Similar to carbamates, organophosphates and pyrethroids, neonicotinoids have been some of the most extensively used chemicals in the green industry. A large number of products and formulations containing neonicotinoids, and products that combine neonicotinoids with pyrethroids or other chemicals, are available for the green industry. Neonicotinoids and other insecticides, when used in violation of label instructions, can cause significant detriment to the survival and health of individual pollinators and their colonies (*see above*). Applicators of insecticides and their supervisors are advised to follow label restrictions and precautions faithfully.

GROUP 5 INSECTICIDE

GROUP MODE OF ACTION

Neonicotinic acetylchlorine receptors and allosteric modulators

IRAC CHEMICAL SUBGROUPS[1]

Spinosyns

General Group Profile

Spinosyns have contact and ingestion activity against a wide range of chewing and sucking insect pests. Target pests often stop feeding and moving within hours of contact with insecticide residue, and they die soon after contact. The activity of spinosyns is greater against larvae than it is against adults. Spinosyns have no systemic activity.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

spinosad, spinetoram

How the Chemistry Works Within the Pest

Spinosyns disrupt binding at the nicotinic acetylchlorine receptors causing prolonged stimulation of the nervous system. In contrast to neonicotinoids, which bind directly to the receptor, spinosyns affect receptors allosterically, or by binding to a part of the receptor and changing their shape. Metabolites bind to the Da6 subunit and change the shape of the nicotinic acetylchlorine receptor, which affects its ability to function. Spinosyns are also antagonistic to GABA-gated ion channels.

How You Might Observe that Treatments are Working

Treated insects are first hyper-excited, then become paralyzed leading to death.

General Notes on Target Arthropods

Effective for managing caterpillars, leaf-miners and thrips in turfgrass and ornamental crops. Additional target pests include whiteflies, leaf-feeding beetles, fungus gnats, shore flies, fire ants, and spider mites.

Notes on Interactions with Non-Target Arthropods

Spinosad and spinetoram have low environmental and mammalian toxicology profiles, so is registered by EPA as a reduced risk insecticide. Spinosad, when sprayed, is toxic to parasitoid wasps and bees but has less effect on lady beetles, lacewings and predatory bugs.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

Additional Notes for Optimal Deployment

Spinosyns do not have systemic activity, therefore, thorough coverage of the plant canopy is recommended. These chemicals are also more effective against larvae than adults. Careful timing of application is therefore recommended so the insecticide is applied during the most vulnerable life stage or developmental time during a target pest's life cycle. For target pests with overlapping generations, repeated applications or (preferably) rotation with another MOA is highly recommended.

Origin and History

Described by Eli Lilly scientists in 1986 as a byproduct produced by *Saccharopolyspora spinosa,* which is an actinomycete bacterium. Two major metabolites of *S. spinosa*: spinosyn A and spinosyn D, are responsible for the insecticidal activity. In 1989, the Ag Product division of Eli Lilly merged with Dow Chemical Company into DowElanco (now Dow AgroSciences). A fermentation facility was built to mass-produce the insecticide. The name 'spinosad' is derived by combining *spinosa* with A and D metabolites. The same fermentation products that yielded spinosad were further developed and modified, resulting in the discovery of spinetoram by Dow AgroSciences. Because of the artificial molecular structural modifications, spinetoram is considered 'semi-synthetic.' Spinetoram is registered in the US in 2007 under EPA's Reduced Risk Pesticide Initiative. Dow introduced spinetoram in a combination product with sulfoxaflor (XXpire) to the ornamental industry in 2014.

Current Status

Spinosad (Entrust & Conserve SC, Dow AgroSciences) has been approved for use on USDA certified organic produce. The intensity and frequency of the use of Conserve SC has led to the development of resistance in some regions of the US In late 2008, Dow AgroSciences suspended the sale and use of spinosad in Broward and Palm Beach County, Florida, due to resistance development in western flower thrips. Dow introduced spinetoram (in a combination product with sulfoxaflor) to the ornamental industry in 2014.

GROUP 6 INSECTICIDE

GROUP MODE OF ACTION

Allosteric modulators of GABA chlorine channels

IRAC CHEMICAL SUBGROUPS[1]

Avermectins, Milbemycins

General Group Profile

Abamectin and milbemectin have contact and translaminar activity. Translaminar activity provides a measure of control against mites feeding on the underside of leaf or leafminers feeding between leaf epidermises even if only upper leaf surfaces are treated. Emamectin benzoate has systemic activity, which allows this compound to be formulated for trunk injection for wood boring insects and sucking insects control in urban landscape, as well as caterpillars, leafmining flies and spider mites in nurseries.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

abamectin[2], emamectin benzoate, milbemectin

How the Chemistry Works Within the Pest

Thought to be blockers of the GABA receptor, avermectins and milbemycins are now known to induce opening of glutamate-gated chlorine channels of nerve cells. When the compounds attach allosterically to the receptor, the chlorine channel is activated and chlorine ions continue to flow into the nerve cells, resulting in continuous excitation of the nervous system.

How You Might Observe that Treatments are Working

Prolonged opening of the chlorine channels lead to convulsion, paralysis and death.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

[2] For professional management of root-feeding nematodes on turfgrasses in greens and tees, Avid (abamectin) has received Special Local Needs (24C) registration in multiple states, including AL, FL, GA, LA, MS, NC, SC, TN and VA in the southeastern US.

General Notes on Target Arthropods

Abamectin is effective against immature and adult spider mites, eriophyid mites, broad mite and cyclamen mite (eggs are generally not killed), thrips, whiteflies and leafminers. Milbemectin is currently registered for control of all life stages of various spider mite species in outdoor nursery stock.

Interactions with Non-Target Arthropods

Although this group of chemicals has a low mammalian toxicity, their toxicity to fish and aquatic invertebrates is high. Label instructions regarding site restrictions and buffer zones should be followed. This group of compounds is generally not compatible with entomopathogenic nematodes, or small, soft-bodied biological control agents, such as predatory mite species, parasitoids and minute pirate bugs. Compounds have better compatibility profiles with larger, more robust biological control agents including lady beetles and lacewing larvae. Check with biological control agent suppliers for more details.

Origin and History

The actinomycete bacteria, *Streptomyces avermectinius*, from soil samples collected in 1978 at Ito City, Japan. Avermectin, which was isolated from fermentation broth, showed insecticidal activity. Abamectin is a mixture of avermectin B1a and B1b. Emamectin benzoate is a benzoate salt derivative of abamectin. Milbemycins are the metabolites of fermentation by *Streptomyces hygroscopius*, a species discovered in the soil of Hokkaido, Japan.

Current Status

Several insecticides and fire ant baits containing abamectin are currently registered for the green industry. Ultiflora is the only miticide containing milbemectin. Trunk injection of emamectin benzoate (TREE-äge; Syngenta) is effective at managing the invasive emerald ask borer. Enfold (5 percent emamectin benzoate) was introduced by Syngenta for ornamental nurseries in 2014.

GROUP 7 INSECTICIDE

GROUP MODE OF ACTION

Juvenile hormone mimics

IRAC CHEMICAL SUBGROUPS[1]

Juvenile hormone analogues (7A); Fenoxycarb (7B); Pyriproxyfen (7C)

General Group Profile

Juvenile hormone (JH) mimics are insect growth regulators that have broad-spectrum activity against many pest species because the target process (i.e., metamorphosis) of these compounds is synthesized naturally by insects and crucial to their developmental processes.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(7A) s-kinoprene, s-methoprene; (7B) fenoxycarb; (7C) pyriproxyfen

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How the Chemistry Works Within the Pest

JH mimics kill insects by modifying or arresting development of immature insects, or by stopping adult reproduction. Most commonly, JH mimics disrupt metamorphosis, molting and exoskeleton formation. For this reason, JH mimics will be most effective at replacing true juvenile hormones that are crucial to physiological processing related to successful molting and development.

How You Might Observe that Treatments are Working

Insects exposed to juvenile hormone mimics at a vulnerable developmental stage (usually as larvae) may stop feeding and maturing and can develop a mixture of larval/pupal or larval/adult characteristics that generally leads to quick death.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Methoprene and fenoxycarb are effective against imported fire ants and other nuisance ants. Fenoxycarb has additional efficacy against sucking insects, caterpillars, leafminers, thrips and weevils. s-kinoprene is very effective against soft-bodied sucking insects, including aphids, whiteflies, scale insects and mealybugs. Pyriproxyfen is used to control whiteflies, scale insects, mealybugs and leafminers on indoor and outdoor ornamental plants.

Notes on Interactions with Non-Target Arthropods

Juvenile hormone mimics have low mammalian toxicity and provide environmental safety, due in part, to target specificity. These products are therefore classified as reduced risk pesticides by US EPA. JH mimics have low toxicity to many beneficial arthropods, including predatory mite, parasitoids, lady beetles, lacewings and minute pirate bugs; thus, they are ideal for inclusion into an IPM program. However, because of potential impact on immature biological control agents, JH mimics should be used carefully when the biological control program is heavily reliant upon immature predators.

Additional Notes for Optimal Deployment

JH mimics disrupt normal development and consequently must be applied against immature life stages. Therefore, careful timing of the application is crucial to the success of the management programs. Recent studies suggest that repeated applications of pyriproxyfen are effective in managing some hard-to-control armored scale species on ornamental trees and shrubs, if the application is timed to control the crawlers (i.e., the hatchlings) .

Origin and History

Insect growth regulators (IGRs), including JH mimics, were developed in the 1960s as a response to toxicological and environmental concerns about organophosphates and carbamates. Methoprene was the first juvenile hormone analogue marketed in the US.

Current Status

Pyriproxyfen and s-methoprene are formulated as fire ant baits, whereas fenoxycarb was replaced by abamectin in the most current formulation of Award II fire ant bait. Preclude TR is currently the only product containing fenoxycarb and is registered for greenhouse uses only.

GROUP 8 INSECTICIDE

GROUP MODE OF ACTION

Miscellaneous non-specific (multi-site) inhibitors

IRAC CHEMICAL SUBGROUPS[1]

Fluorides (8C), Borates (8D)

General Group Profile

Generally considered an inorganic insecticide, cryolite is a fluoride salt. It is a stable chemical that does not evaporate but can dissolve quickly in water to enable topical applications. Cryolite becomes active through ingestion. This compound has relative short residual longevity and low toxicity to non-target organisms, including mammals. Typically, multiple applications at high application rates are needed to achieve sufficient control of the target pests. Borax (boric acid and boron- or borate-containing salts) is generally considered an inorganic pesticide. It is a low toxicity mineral that does not volatilize easily. Borax has a broad range of activity against insects, fungi and weeds. This is a group of very slow acting general pesticides. As insecticides, borax acts through ingestion and as a disruptor of insect water balance.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(8C) sodium aluminofluoride (= cryolite); (8D)sodium tetraborate decahydrate

How the Chemistry Works Within the Pest

Once inside the insect body, cryolite disassociates and releases the fluoride ions. The fluoride ions inhibit many iron-, calcium- and magnesium-containing enzymes that are involved in energy production in cells. The exact target site and protein, and thus the mode of action, of cryolite are not specifically identified. The exact target site and mode of action of borate-containing insecticides are not known. It is generally believed that borax kills insects in two ways. First, borax is a stomach poison. When formulated as baits, borax can be ingested by insects. Once inside the insect body, borate interferes with the normal functions of enzymes or physiological processes. Borax can also be formulated as topical sprays. Once the spray solution covers the arthropod body, borate in the solution begins to absorb insect cuticle waxes. With the loss of the protective waxy layer on the cuticle, insects quickly begin to lose water and eventually die from desiccation.

How You Might Observe that Treatments are Working

Insects will slowly die following ingestion of cryolite. Insects coated by borate often convulse or twitch. Death often occurs within a day.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Cryolite is used to control leaf-feeding beetles and caterpillars on ornamental and shade trees in the landscape. Borate-containing products have a broad spectrum of pesticidal activity. Most products are registered as general pesticides and have activity against insects, mites, diseases and other pests. Registered target pests include soft-bodied insects, such as aphids, mealybugs, whiteflies, scale insects, psyllids, plant bugs, leafhoppers, mites, thrips and caterpillars.

Notes on Interactions with Non-Target Arthropods

Cryolite is generally considered harmless to non-target organisms and biological control agents. Borax is safe to mammals so long as dusts used for household applications do not become airborne. The compatibility of borax with biological control agents and pollinators is not well known. It is advisable not to spray borax solution directly onto a population of a desirable organism.

Additional Notes for Optimal Deployment

Because borax does not have residual toxicity, repeated topical applications are recommended.

Origin and History

Cryolite, used as an ore of aluminum, was first registered as an insecticide in the US in 1957. Boric acid was used extensively for control of cockroaches and crawling household pests during the 1930s and 1940s. After a long period of inactivity, several additional borax-containing pesticides were registered in 1980s and 1990s.

Current Status

The predominant uses of cryolite are for the management of leaf-feeding insects on grapes, potatoes and citrus; uses on ornamental plants are considered minor. Currently, only one product (Kryocide) is registered for use on landscape ornamental plants. Few borate-containing products are registered for uses on ornamental plants. One such product is Prev-Am Ultra, a general insecticide, miticide and fungicide.

GROUP 9 INSECTICIDE

GROUP MODE OF ACTION

Chorodontal organ TRPV channel modulators

IRAC CHEMICAL SUBGROUPS[1]

Pyridine azomethine derivatives (9B)

General Group Profile

These compounds affect the nervous system associated with feeding behavior of sucking insects. Although pymetrozine is known to have translaminar and systemic activities, the compound often binds tightly to organic matter in potting medium and becomes unavailable for absorption. Therefore, pymetrozine is not labeled for soil drench in typical ornamental plant production systems. Pyrifluquinazon has contact and translaminar activity.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(9B) pymetrozine, pyrifluquinazon

How the Chemistry Works Within the Pest

Pymetrozine and pyrifluquinazon are proteins that work by interfering with the neurochemical processes that are associated with feeding. By interfering with nervous signals (through serotonin or chorodontal mechanoreceptors) that regulate fluid uptake by mouthparts, feeding behavior of sucking insects is effectively inhibited within hours. Exposed pests starve to death in the next few days.

How You Might Observe that Treatments are Working

Because pymetrozine does not have direct insecticidal activity, products do not kill sucking insects with quick knockdown. Mortality may be observed 36-40 hours after application. Whiteflies treated with pyrifluquinazon die within two days of application.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Pymetrozine is a pest-specific insecticide that is only effective against sucking insects, like aphids, whiteflies and mealybugs, and thrips. Pyrifluquinazon label includes uses against aphids, chilli thrips, leafhoppers, mealybugs and whiteflies.

Interactions with Non-Target Arthropods

The highly specific activity of feeding blockers in homopteran pests results in low lethal or sub-lethal activity to predators and parasitoids used in biological control programs, as well as limited ecotoxological profiles. Pyrifluquinazon is reported to be "gentle on both beneficial insects and pollinators," yet compatibility of with commonly used biological control agents remains to be investigated.

Additional Notes for Optimal Deployment

Although pyrifluquinazon has translaminar activity, the product should be applied thoroughly to achieve full coverage of the canopy.

Origin and History

Developed in the 1980s, pymetrozine was introduced to the ornamental market by Syngenta in 1999. Pyrifluquinazon was developed by Nichino America (a subsidiary of Nihon Nohyaku Co. Ltd. in Japan). The product was introduced to the US ornamentals market by SePRO in 2014.

Current Status

Endeavor (pymetrozine) is currently available for management of sucking insects in greenhouses, interiorscapes, nurseries and landscape ornamentals. Rycar (pyrifluquinazon) is currently registered for uses in greenhouse. No outdoor uses are allowed

GROUP 10 INSECTICIDE

GROUP MODE OF ACTION

Mite growth inhibitors

IRAC CHEMICAL SUBGROUPS[1]

Clofentezine, Hexythiazox (10A);
Etoxazole (10B)

General Group Profile

As slow-acting mite growth regulators, clofentezine, hexythiazox and etoxazole affect only the eggs and immature spider mites, with no direct effect on adult mites. However, eggs deposited by the adult mites will be poisoned and killed by the residue. These compounds typically have long residual activity (28-45 days).

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(10A) clofentezine, hexythiazox, (10B) etoxazole

How the Chemistry Works Within the Pest

Mite growth inhibitors interfere with chitin synthesis during the molting process. Both embryo development and larval maturation can be disrupted. The specific target site or proteins responsible for such inhibition is unknown.

How You Might Observe that Treatments are Working

Because mite growth regulators work through the developmental processes of spider mites, these products do not cause quick knockdown of the mite population. Instead, mites will begin to die a few days after the application.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Products containing these three chemistries are contact miticides that provide efficacy against eggs and immature life stages of spider mites. These products have low to no efficacy against broad, cyclamen and eriophyid mites.

Notes on Interactions with Non-Target Arthropods

These miticides are spider mite-specific; therefore, they are compatible with many predatory mites, including many species of the family Phytoseidae that are used for biological control. Impacts on other predators, parasitoids, invertebrates and mammals are also limited.

Additional Notes for Optimal Deployment

These miticides have only contact activity; therefore, complete and even coverage of all plant surfaces is very important to achieve control. Since the products are more effective against eggs and larvae that emerged during the effective residual period, application should be conducted as early in the infestation process as possible. In situations of mixed life stages, another miticide with activity against adults may have to be applied before the mite growth inhibitors or used in a tank mix. Do not rotate among these three active ingredients in a pesticide rotation program.

Origin and History

Development of clofentezine, hexythiozox and etoxazole began in the mid- to late 1980s. Market commercialization occurred in the early to late 1990s.

Current Status

Currently, four products are available to the ornamental industry — Ovation SC (clofentezine), Hexygon DF (hezythiazox), Beethoven TR (etoxazole) and TetraSan 5 WDG (etoxazole) — for control of spider mites in indoor and/or outdoor areas.

GROUP 11 INSECTICIDE

GROUP MODE OF ACTION

Microbial disruptors of insect midgut membranes

IRAC CHEMICAL SUBGROUPS[1]

Bacillus thuringiensis (*Bt*) and the insecticidal proteins they produce (11A); *Bacillus sphaericus* (11B)

General Group Profile

Bacillus sphaericus and *Bt* subspecies *israelensis* are primarily used for biological control of mosquito, blackfly, biting fly and midge larvae in lakes, ponds, marshes, and other natural or artificial water bodies. Currently, products containing *Bacillus sphaericus* are not available to the ornamental industry; therefore, these products will not be discussed in this publication. *Bt* requires ingestion of the bacterial spores or proteins by the target pests to be effective. *Bt* is also more effective against immature insects than adults.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(11A) *Bacillus thuringiensis* (*Bt*) subspecies *aizawai*, *Bt* ssp. *israelensis*, *Bt* ssp. *kurstaki*, *Bt* ssp. *tenebrionis*

How the Chemistry Works Within the Pest

Insecticidal properties of *Bt* are not due to direct pathogenicity, but are affected by release, upon ingestion, of crystal delta-endotoxins (or *Cry* proteins), that are produced by these bacteria. Within the insect digestive tract, the alkaline pH and insect's gut enzymes degrade the crystals into their three constituent components, thus activating the endotoxins. The central domain binds to receptor sites on insect midgut membranes and forms porous cation channels that disrupt the potassium ion and pH balances on either side of the membrane. The rise of pH in the blood (haemolymph) of insects results in paralysis and eventual death of the insect.

How You Might Observe that Treatments are Working

Insect larvae stop eating and become lethargic then limp.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Each *Bt* subspecies has targeted specificity to a select group of insects, so it is important to know the target pest and the effective control spectrum for individual *Bt* products. *Bt* ssp. *israelensis* controls fungus gnats in greenhouse ornamentals and (some) vegetable production. *Bt* ssp. *aizawai* and *Bt* ssp. *kurstaki* target caterpillars, including armyworms, azalea caterpillar, budworms, diamondback moth, Florida fern caterpillar, hornworms, *Heliothis* caterpillars, leaf-rollers, loopers, oleander caterpillar, sod webworms and others. It is critical to apply the products against small caterpillars. Novodor is the only product containing *Bt* *tenebrionis*. It is used for control of elm leaf beetles on shade trees and other ornamental plants and Colorado potato beetle on potato, tomato and eggplant.

Notes on Interactions with Non-Target Arthropods

Because of their high level of target specificity and an absence of toxicity against human and other animals, *Bt* products are used as biological control agents, considered environmentally friendly, and accepted by all organic certification programs. *Bt* is compatible to all commercially available biological control agents.

Additional Notes for Optimal Deployment

Most *Bt* products are formulated as granules, baits, pellets or briquettes, while some can be applied as foliar spray solutions. *Bt* products are only effective against actively feeding insects and product efficacy decreases as insects mature and grow larger. Reapplications of products containing *Bt* are often necessary within 1-4 weeks as the products break down and lose efficacy. Because formulated products may contain live bacteria and spores, it is important to follow label directions regarding storage, particularly in avoiding exposure to direct sunlight and high temperatures.

Origin and History

Bt was first discovered in 1902 by Japanese biologist Shigetane Ishiwatari and described in 1911 by German scientist Ernst Berliner. *Bt* naturally occurs in the soil, on leaf surfaces and within ground- and standing water. Insecticides containing spores or endotoxins of *Bt* were introduced in the 1920s. In 1976, the *cry* gene was detected within the circular string of DNA in the bacterial plasmid and determined to be responsible for endotoxin production. Many other *Cry* proteins and *cry* genes are now known. In 1985, *cry* genes were isolated and inserted into plant genes, after which, the genetically modified (GM) plants were capable of producing the endotoxins or *Cry* proteins just like *Bt* bacteria. Since 1996, *Bt*-corn and cotton have been widely planted across the US.

Current Status

A large number of *Bt* ssp. *aizawai* and *Bt* spp. *kurstaki* products are registered for caterpillar management in agricultural, commercial and residential settings. Gnatrol (*Bt* ssp. *isrealensis*) is registered for fungus gnat and shore fly management in greenhouses, interiorscapes and nurseries, whereas Novodor (*Bt* ssp. *tenebrionis*) is registered for elm leaf beetle control on shade and ornamental trees.

GROUP 12 INSECTICIDE

GROUP MODE OF ACTION

Inhibitors of mitochondrial ATP synthase

IRAC CHEMICAL SUBGROUPS[1]

Organotin miticides (12B)

General Group Profile

Fenbutatin-oxide generally has low acute and chronic mammalian toxicities and non-carcinogenic to human. However, it is known to be a severe eye irritant (therefore considered by EPA to be of high acute toxicity) and highly toxic to aquatic organisms. Thus, fenbutatin-oxide is registered as a restricted use pesticide.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(12B) fenbutatin-oxide (a.k.a. hexakis)

How the Chemistry Works Within the Pest

Plants and animals have hundreds of mitochondria maintained within each individual cell. Mitochondria convert chemical energy released during nutrient breakdown into cellular energy, in the form of adenosine triphosphate (ATP). This metabolic process, called oxidative phosphorylation, occurs within the innermost matrix of a mitochondrion. ATP is then transported throughout the body for use in many physiological functions. Fenbutatin-oxide works by inhibiting the actions of ATP synthase and disrupting the production of ATP.

How You Might Observe that Treatments are Working

Although highly effective and with long residual toxicity (about 30 days), organotin miticides usually cause mortality in spider mite populations 7-10 days after the application.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Fenbutatin-oxide is currently registered for control of spider mites (twospotted, southern red, spruce, oak mites) and clover mite in greenhouses, nurseries and landscapes.

Notes on Interactions with Non-Target Arthropods

Fenbutatin-oxide is compatible to predatory mites, lady beetles, lacewings, minute pirate bug and other biological control agents. Fenbutatin-oxide is practically nontoxic to bees when the spray solution has dried. The compound is considered highly toxic to fish, aquatic invertebrates, birds and mammals; therefore, avoid using the product near water or where runoff is likely to occur.

Additional Notes for Optimal Deployment

Fenbutatin-oxide is a contact miticide. Thorough coverage of the canopy is required for an effective treatment. Fenbutatin-oxide performs better at higher temperatured. Application of fenbutatin-oxide should only be made when the temperature at the time of application is above 70 degrees F.

Origin and History

The fungicidal, acaricidal, insecticidal and molluscidal activities of organic compounds of tin were discovered in the 1950s. Fenbutatin-oxide is an organotin miticide first developed in the 1960s. EPA granted registration of fenbutatin-oxide miticide in 1974.

Current Status

Currently, fenbutatin-oxide (Meraz and ProMITE) is available as a restricted use miticide registered for uses on ornamental plants in greenhouses, nurseries and landscape. Vendex is registered for Christmas tree production in Oregon and Washington only. Meraz and ProMITE are formulated in water-soluble packages to reduce exposure to workers during handling and mixing. Resistance to fenbutation-oxide has been reported in twospotted spider mite populations in outdoor fruit production. Resistance in ornamental production has not been reported.

GROUP 13 INSECTICIDE

GROUP MODE OF ACTION

Uncoupler of oxidative phosphorylation via disruption of the proton gradient

IRAC CHEMICAL SUBGROUPS[1]

Chlorfenapyr

General Group Profile

Often considered a member of the chemical class pyrroles, chlorfenapyr is a pro-insecticide (i.e., an insecticide that becomes active only after entering the insect body).

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

chlorfenapyr

How the Chemistry Works Within the Pest

Oxidative phosphorylation is the process by which mitochondria produce cellular energy from nutrient breakdown (*see Group 12*). Once inside an insect's body, chlorfenapyr is converted to the biologically active compound CL 303268. CL 303268 disrupts the proton gradient that is essential to normal functioning of oxidative phosphorylation across the mitochondrial matrix, thus disconnects the actions of the electron transport chain. As a result, the production of ATP is inhibited.

How You Might Observe that Treatments are Working

Mortality typically occurs within 72 hours of application.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Target pests include spider mites, broad mite, cyclamen mite, rust mite, caterpillars, fungus gnats and thrips, as well as foliar nematodes on greenhouse-grown plants.

Notes on Interactions with Non-Target Arthropods

Chlorfenapyr is not registered for outdoor uses because of concerns over its high reproductive toxicity against birds. Exposure to birds and other wildlife is low or nonexistent when the compound is used in greenhouses. Based on current research, chlorfenapyr has inconsistent effects on the survival of various groups of biological control agents. Cloyd et al. (2006; HortScience 41: 707-710) showed that survival of the predatory mite *Phytoseiulus persimilis* was reduced, whereas that of the other predatory mite *Neoseiulus californicus* was not. Sterk et al. (2003; Proceedings of the First International Symposium on Biological Control of Arthropods) reported that chlorfenapyr was highly toxic to *P. persimilis* adults, *Encarsia formosa* adults and *Macrolophus caliginosus* larvae, while the impact on *Orius laevigatus* larvae and *E. formosa* pupae was minimal. Additional studies are needed before we can reach a conclusion on the compatibility of chlorfenapyr with biological control agents.

Additional Notes for Optimal Deployment

Chlorfenapyr has both translaminar and contact activities against immature and adult mites and insects. Thorough coverage of the entire plant is recommended for successful management. Chlorfenapyr has limited efficacy against eggs; therefore, another miticide with ovicidal activity should be included in the tank mix or rotation program. Alternatively, make a second application 5-7 days later.

Origin and History

Chlorfenapyr was discovered as a toxin produced by the actinomycete bacterium *Streptomyces fumanus* in 1985. American Cyanamid (now BASF) developed the compound as an agricultural product in the 1990s. The compound was registered for uses on greenhouse-grown ornamental plants in the US in 2001. Originally marketed by OHP, the marketing right was transferred to BASF in 2009.

Current Status

Pylon is currently the only product containing chlorfenapyr registered for uses on ornamental plants. No outdoor uses of Pylon are allowed in the US.

GROUP 14 INSECTICIDE

GROUP MODE OF ACTION

Inhibitors of chitin biosynthesis, type 0

IRAC CHEMICAL SUBGROUPS[1]

Benzoylureas

General Group Profile

Benzoylureas are insect growth regulators that enter target pests through contact and ingestion. The compounds do not have systemic or translaminar activity in plant tissues. Because chitin biosynthesis inhibitors interfere with the molting process and only immature arthropods molt, these chemicals are most effectively against larvae and nymphs.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

diflubenzuron, novaluron

How the Chemistry Works Within the Pest

Type 0 chitin biosynthesis inhibitors interfere with chitin production and exoskeleton formation by causing the new exoskeleton to fail to form or form incorrectly. Protective and supportive functions are lost, leading to insect death. The receptor proteins or biochemical functions that the chitin biosynthesis inhibitors target are unknown at this time.

How You Might Observe that Treatments are Working

Affected insects are deformed and die slowly across time.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Products containing diflubenzuron and novaluron are currently labeled for management of caterpillars, whiteflies, fungus gnats, shore flies, leafminers and thrips on ornamental plants.

Notes on Interactions with Non-Target Arthropods

Diflubenzuron and novaluron have low toxicity against many beneficial organisms used in biological control programs, including *Amblyseius swirskii* and *Hypoaspis* spp. predatory mites, lacewings, *Eretmocerus* spp. parasitoid wasps, nematodes and entomopathogenic fungi. Application of diflubenzuron should be avoided if minute pirate bugs have been released because of high toxicity when directly sprayed.

Additional Notes for Optimal Deployment

Diflubenzuron and novaluron are insect growth regulators and should be used against immature insects. Apply to achieve uniform coverage of the foliage. When used against fungus gnats and shore flies, diflubenzuron should be applied to wet the soil medium.

Origin and History

Diflubenzuron was first discovered in 1972 and introduced in the US in 1979. Additional benzoylureas were discovered during the process of optimizing and synthesizing analogues of diflubenzuron. Novaluron was discovered during the optimization process and was used as an insecticide in South Africa, Argentina and Australia before it was the labeled for the US ornamental industry in 2001.

Current Status

Adept and Dimilin (diflubenzuron) are currently registered for uses in greenhouses and interiorscapes, whereas Pedestal (novaluron) is registered for uses in outdoor nurseries, shadehouses and greenhouses.

GROUP 16 INSECTICIDE

GROUP MODE OF ACTION

Inhibitors chitin biosynthesis, type 1

IRAC CHEMICAL SUBGROUPS[1]

Buprofezin

General Group Profile

Similar to benzoylureas, buprofezin is an insect growth regulator that does not have systemic activity in plant tissues. Target pests are exposed to buprofezin through contact, ingestion and spiracular uptake of volatilized product. Buprofezin has activity against survival of immature insects and reproduction of adult insects.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

buprofezin

How the Chemistry Works Within the Pest

Buprofezin inhibits chitin synthesis and successful deposition of chitin in forming the insect exocuticle. Insect cuticle affected by buprofezin becomes inelastic and brittle. Buprofezin also suppresses reproduction in adults or induces adults to deposit sterile egg.

How You Might Observe that Treatments are Working

Treated insects die shortly after they next molt, often trapped within the old skin.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Type 1 chitin biosynthesis inhibitors are primarily effective against immature homopteran pests (whiteflies, mealybugs, leafhoppers, planthoppers, psyllids, soft scales, armored scales and cottony cushion scales).

Notes on Interactions with Non-Target Arthropods

Buprofezin has low toxicity against predatory mites, parasitoids, lacewings, lady beetles and minute pirate bugs. High toxicity of buprofezin to the larvae of predatory midges (*Aphidoletes aphidimyza*) has been documented; so, avoid application of buprofezin in greenhouses where the predatory midges are in use for aphid management.

Additional Notes for Optimal Deployment

Because buprofezin does not directly reduce adult survival, applicators should consider tank mixing buprofezin with another chemical that has adulticidal activity, or buprofezin can be rotated with another insecticide. Repeated applications across multiple years, of a combination of horticultural oil and buprofezin, have helped suppress armored scales populations feeding on twigs of plants. Applications should coincide with timing of immature crawlers activity. Good spray coverage of the potting medium, (e.g., for fungus gnat and shore fly control) and plant canopy is essential.

Origin and History

Discovery and development of buprofezin began in Japan in the 1970s and the products were first marketed in the 1980s by Nihon Nohyaku Co., Ltd. Buprofezin was used successfully in Asia to combat infestations by brown planthoppers in rice. Buprofezin was introduced to the ornamental industry in the US in 2004.

Current Status

Talus 70DF is currently the only product containing buprofezin registered for uses on ornamental plants. Talus 70WP and Talus 40SC are older formulations of the same chemical.

GROUP 17 INSECTICIDE

GROUP MODE OF ACTION

Dipteran molting disruptors

IRAC CHEMICAL SUBGROUPS[1]

Cyromazine

General Group Profile

Sometime considered a member of the insecticide class triazines, cyromazine is an insect growth regulator with a narrow specificity against immature dipteran larvae.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

cyromazine

How the Chemistry Works Within the Pest

The exact mechanism in which cyromazine interfere with the biochemical processes of insect molting is unknown. Cyromazine may interfere with the molting hormone, 20-hydroxyecdysone. Larvae are poisoned after ingesting treated plant tissues and algae that are used as food resources.

How You Might Observe that Treatments are Working

Development of the fly larvae is arrested and eventually the larvae die.

General Notes on Target Arthropods

This chemical is only effective against dipteran (fly) pests, including leafminers, fungus gnats and shore flies. Most effective when used with another chemical/practice to control adult flies.

Interactions with Non-Target Arthropods

Cyromazine is compatible with predatory mites, parasitoids and predators (like lady beetles, lacewings and minute pirate bugs) used in biological control programs.

Additional Notes for Optimal Deployment

Sprays should be directed toward the surfaces where immature larvae feed and develop. These surfaces include leaf surface where leafminer larvae are active, and surfaces of substrate or potting medium, benches and ground around production areas. Treat locations that stay continually moist, thus promoting algal growth, where fungus gnats and shore flies are active. This compound has no direct effect on adults, therefore, tank mix or rotate with another adulticidal product.

Origin and History

The insect growth regulating activity of cyromazine was described in 1980 and developed by Ciba-Geigy Ag (now Syngenta Ag). EPA's initial registration (1984) and ornamental plant uses were approved in 1990.

Current Status

Citation is currently the only product containing cyromazine that is registered for use on greenhouse, indoor and landscape ornamental plants and vegetables.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

GROUP 18 INSECTICIDE

GROUP MODE OF ACTION

Ecdysone receptor antagonists

IRAC CHEMICAL SUBGROUPS[1]

Diacylhydrazines

General Group Profile

Diacylhydrazines are also insect growth regulators with stomach and contact activity, and high efficacy against caterpillars. Compounds from this group are only effective when ingested by the caterpillars. Therefore, effective use of this chemical relies on timing applications to coincide with insect feeding activity during susceptible juvenile life stages.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

tebufenozide

How the Chemistry Works Within the Pest

These compounds interfere with normal functioning of ecdysone receptors by binding to ecdysone receptors and accelerating the biochemical processes of larval molting. Repeated molting before larvae are ready and have achieved normal growth depletes resources and leads to death. Tefubenozide may also disrupt the development of ovaries in caterpillars.

How You Might Observe that Treatments are Working

Affected insects often show deformations and delays in development. This is a slow-acting insecticide; mortality may not become noticeable for days after application.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Tebufenozide is most useful for managing caterpillar species. Halofenozide (Mach 2) is registered for caterpillar and white grub management in commercial turfgrass sites, which include commercial lawns and grounds.

Notes on Interactions with Non-Target Arthropods

Because of its specificity against caterpillars, tebufenozide is very safe for humans, pets and other non-target animals. Tebufenozide is compatible with predatory mites, lacewing, predatory bug (*Macrolophus caliginosus*) and minute pirate bugs.

Origin and History

Scientists at Rohm and Haas Company discovered the first diacylhydrazine in 1983. Through additional modifications, a more potent analogue, tebufenozide, was discovered in 1986. Tebufenozide was introduced in the US in 1994 and was mainly used for management of caterpillars on agricultural crops.

Current Status

Confirm 2F is currently registered for uses on nursery-grown ornamental plants and Confirm 240 includes registered uses for greenhouse and nursery grown fruiting ornamental plants. Mach 2 is registered for use in commercial turfgrass sites.

GROUP 20 INSECTICIDE

GROUP MODE OF ACTION

Mitochondrial complex III electron transport inhibitors

IRAC CHEMICAL SUBGROUPS[1]

Hydramethylnon (20A); Acequinocyl (20B), Bifenazate (20D)

General Group Profile

Hydramethylnon is a stomach poison that is typically formulated as baits for ants and cockroaches. Mites are exposed to acequinocyl mainly through contact activity, although there are also some activities through ingestion. Prior to being metabolized following contact, acequinocyl is inactive and the compound must be converted to its deacetylated metabolite for toxicant action to occur. Feeding inhibition following ingestion of hydramethylnon and conversion of acequinocyl needed to activate toxicity, results in slower time to mortality of pests by both compounds.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(20A) hydramethylnon; (20B) acequinocyl; (20D) bifenazate

How the Chemistry Works Within the Pest

Pest cellular mitochondria convert chemicals in food into energy that can be used to power other metabolic processes in cells. Electrons released from digested food pass through a series of membranes within the innermost part (matrix) of a mitochondrion, then activate ionic pumps to create a proton and energy gradient. Under normal conditions, as protons reenter the mitochondrion via a protein (ATP synthase) and attempt to balance the gradient, energy in the form of adenosine triphosphate (ATP) is produced and then transported for use in other cellular functions. Group 20 (and 21) compounds inhibit the normal functions of electron transport complexes by binding to cytochrome. These cytorchrome proteins facilitate electron transport and enable reduction-oxidation reactions. Cytochrome organization within the mitochondrial electron transport complex allows electrons to be transported down the various membranes. Compounds are classified as effecting Electron Transport Complex I (Group 21), II (some activity among Group 25 compounds) or III (Group 20), depending upon which membrane the chemical targets. Bifenazate acts on the cytochrome B-complex III metabolic pathway, thus disrupting normal energy production in mitochondria of mites.

How You Might Observe that Treatments are Working

Once treated, insects and mites survive briefly, becoming less active as their existing energy resources are depleted. Bifenazate causes rapid cessation of feeding and mortality in spider mite populations.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Hydramethylnon is primarily used to manage nuisance and imported fire ants in the landscapes and nurseries. Acequinocyl is mainly a contact miticide with activity against several spider mite species. Acequinocyl is effective against all life stages of mites and has residual activity that exceeds 28 days. Bifenazate is effective against various spider mite species and clover mite on ornamental plants.

Notes on Interactions with Non-Target Arthropods

Effective against spider mites, acequinocyl is compatible with other commonly used predatory mites including *Amblyseius swirskii*, *Amblyseius cucumeris*, *Neoseiuslus californicus*, and *Phytoseiulus persimilis*. Hydramethylnon is toxic to some fish species. Acequinocyl is toxic to aquatic invertebrates. Read product labels carefully and adhere to restrictions on chemigation, buffer zone, drift and runoff, and equipment cleaning procedures. Bifenazate is compatible with many biological control agents, including parasitoids, *Amblyseius* spp. predatory mites, predatory bugs, predatory midges, lady beetles and lacewings. Bifenazate has moderate toxicity to *Phytoseiulus persimilis*, one of the most commonly used biological control agents used against spider mites.

Additional Notes for Optimal Deployment

Ant baits containing hydramethylnon should be applied when ants are foraging. Avoid application just before rain or irrigation. For effective control of spider mites by acequinocyl and bifenazate, good spray coverage on treated plant portions is essential. The recommended application volume is 1000 gallons per acre.

Origin and History

Hydramethylnon was developed by DuPont in 1975 and introduced to ornamentals industry in the 1990s. Acequinocyl was also discovered by DuPont in the 1970s and further developed by Agro-Kanesbo Co. Ltd and Tomen Agro in Japan. Arysta LifeScience first introduced acequinocyl to the ornamentals market in 2005. Bifenazate was first developed by Uniroyal Chemical in 1990 and commercialized by Crompton Corporation in 1999. Bifenazate was introduced to the ornamental market in 2010.

Current Status

Several ant baits containing hydramethylnon are available for landscape and nursery uses to manage imported fire ants and other nuisance ants. Shuttle 15SC (acequinocyl; by Arysta LifeScience) is registered for uses in landscapes and interiorscapes, whereas Shuttle O (acequinocyl; by OHP) is registered for greenhouses and nurseries. Floramite contains bifenazate, whereas Sirocco is a combination product of bifenazate and abamectin. Both products are used for mite control on ornamental plants.

GROUP 21 INSECTICIDE

GROUP MODE OF ACTION

Mitochondrial complex I electron transport inhibitors

IRAC CHEMICAL SUBGROUPS[1]

METI acaricides and insecticides

General Group Profile

Members of this group are mainly contact insecticides and miticides. Fenazaquin, fenpyroximate and pyridaben products have no systemic or translaminar activity. Therefore, good coverage of the treated plant is critical to successful management of pest mite population.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

fenazaquin, fenpyroximate, pyridaben, tolfenpyrad

How the Chemistry Works Within the Pest

These mitochondrial electron transport complex I (thus the acronym MET-I) inhibitors act on proteins associated with mitochondrial electron transport complex I (see description of Group 20 Insecticides). Energy production in mitochondria is effectively curtailed when synthesis of ATP is interrupted.

How You Might Observe that Treatments are Working

Once treated, insects and mites briefly survive, becoming less active as their existing energy resources are depleted.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Fenazaquin has contact activity on whiteflies and controls all life stages of spider mites, rust mite and broad mites. Tolfenpyrad is effective against aphids, leafhoppers, caterpillars (early instar), scale insects, thrips, western flower thrips and whiteflies (on ornamental plants in greenhouses). Fenpyroximate provides up to 21 days of control for all mite life stages for spider mites, broad mite, cyclamen mite, eriophyid mites and mealybugs in greenhouse ornamental production. Pyridaben provides up to 45 days of residual control activity against all spider mite and broad mite life stages and also whiteflies in greenhouse and nurseries.

Notes on Interactions with Non-Target Arthropods

Tolfenpyrad will harm *Hypoaspis aculiefer* and *Amblyseius swirskii* predatory mites that are commercially available and commonly used to manage western flower thrips. Fenpyroximate is reported to be compatible with predatory mites, but pyridaben is not. METI miticides and insecticides are toxic to fish and aquatic invertebrates. Read product labels carefully and adhere to restrictions on chemigation, buffer zones, drift and runoff, and equipment cleaning procedures.

Origin and History

The METI miticides were discovered in the late 1980s and developed between 1991 and 1993. Fenazaquin was discovered by DowElanco Co., first introduced to the fruit production market in the 1990s, and then introduced by Gowan into the US ornamentals market in 2010. Fenpyroximate was discovered by Nihon Nohyaku Co. and introduced to the ornamental market in the US by SePRO in 2000. Pyridaben was discovered by Nissan Chemical Industries and was introduced to US markets by Gowan in 2002. Initially launched in 2002 for uses in outdoor crop production, tolfenpyrad was introduced to the ornamentals market by SePRO in 2011.

Current Status

Several METI miticides and insecticides are registered in the US. Magus (fenazaquin) is registered for uses in landscapes, nurseries, greenhouses and interiorscapes; Akari (fenpyroximate) for nurseries, greenhouses and interiorscapes; Sanmite (pyridaben) for nurseries and greenhouses; and Hachi-Hachi (tolfenpyrad) for greenhouses.

GROUP 22 INSECTICIDE

GROUP MODE OF ACTION

Voltage-dependent sodium channel blockers

IRAC CHEMICAL SUBGROUPS[1]

Indoxacarb (22A); Metaflumizone (22B)

General Group Profile

Indoxacarb has both contact and stomach activities, also larvicidal and ovicidal activities. Indoxacarb is designated a "reduced-risk" pesticide by EPA and considered a good replacement for organophosphates.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

(22A) indoxacarb; (22B) metaflumizone

How the Chemistry Works Within the Pest

Indoxacarb and metaflumizone block the sodium channels on nerve cells, inhibit the inflow of sodium ions, disrupt the ionic balance, and thus interfere with the normal firing of nerve impulses.

How You Might Observe that Treatments are Working

Once an insect is exposed to the chemicals through direct contact or ingestion of treated plant materials, feeding stops almost immediately, followed by paralysis and death over the next few days.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Indoxacarb products include labels for control of European crane fly larvae and grasshoppers, fleas, ants, cockroaches, mole crickets, caterpillars, European pine sawfly larvae and potato leafhopper and sucking insects in urban, household and agricultural production. Bait-type formulations of indoxacarb are activated when ingested and are often more effective against eggs or young caterpillars. Metaflumizone is currently formulated as ant baits for the management of red imported fire ant and other nuisance ant species.

Interactions with Non-Target Arthropods

Although indoxacarb and metaflumizone are nerve poisons, these compounds have low risk and limited environmental toxicological profiles so the EPA considers them reduced-risk insecticides. Indoxacarb and metoflumizone should not be used in indoor ornamentals production systems where biological control agents are used. These compounds are moderately or highly toxic to predatory mites, predatory bugs, lady beetles and lacewings. Applications outdoors should be done carefully and adhere to label restrictions on distance to water (15 ft of fresh water bodies or 60 ft of estuarine water bodies) due to potential detrimental impacts to aquatic organisms.

Additional Notes for Optimal Deployment

Indoxacarb is susceptible to hydrolysis in alkaline water, having half-life of only 1 day in water of pH 9. Check the alkalinity of tap or well water and when needed; add a buffering agent to bring alkaline water pH down to 7. Do not apply baits formulated with indoxacarb and metaflumizone when irrigation or rain is expected within the next 24 hours, or to areas that are exceedingly wet or flooded.

Origin and History

The sodium channel blockers were first discovered by research at Phillips-Duphar B. V. in the Netherlands during the early 1970s. However, early development of commercial insecticides failed because of poor photostability, long persistence in soil and high mammalian toxicity. Indoxacarb was developed by DuPont Agricultural Products in the 1990s and first registered and marketed in US in 2000. In late 2012, Syngenta acquired indoxacarb from DuPont. In the late 1990s, metaflumizone was developed by Nihon Noyaku Co. Ltd. and introduced to the US turf and ornamentals industry by BASF in 2013.

Current Status

Indoxacarb (Advion fire ant bait) and metaflumizone (Siesta fire ant bait) are registered for uses on outdoor landscapes and nurseries. Indoxacarb (Provaunt) is also formulated as a sprayable insecticide for control of several caterpillar species, pine sawflies and leafhoppers on ornamental plants in outdoor and interior landscapes.

GROUP 23 INSECTICIDE

GROUP MODE OF ACTION

Inhibitors of acetyl-CoA carboxylase

IRAC CHEMICAL SUBGROUPS[1]

Tetronic and tetramic acid derivatives

General Group Profile

Spiromesifen has translaminar activity, while spirotetramat is fully systemic (i.e., phloem- and xylem-mobile). As a result, spiromesifen is used as foliar sprays but spirometramat can be used in soil drenches and foliar sprays.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

spiromesifen, spirotetramat

How the Chemistry Works Within the Pest

The enzyme acetyl-CoA plays important roles in normal metabolism and energy production by mitochondria. Acetyl Co-A can also be converted to malonyl-CoA by acetyl-CoA carboxylase, which in turn is used for flavonoid synthesis and elongation of fatty acids yielding protective waxes and cuticle. By targeting acetyl-CoA carboxylase, the Group 23 insecticides shut down lipid, wax and cuticle production. Because waxes and lipid deposits on the surface of insect and mite bodies are crucial to maintaining water balance, their loss causes desiccation of treated insects and mites, leading to their death.

How You Might Observe that Treatments are Working

The affected insects and mites may appear shriveled and dead.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Target pests of spiromesifen include spider mites, tarsonemid mites, tenuipalpid mites, eriophyid mites, and whiteflies. Use of spiromesifen against scale insects is NOT effective. Spirotetramat is effective against adelgids, aphids, leafhoppers, mealybugs, psyllids, rust mites, spider mites, scale insects (crawlers), tarsonemid mites, spittlebugs, thrips (immatures), and whiteflies.

Interactions with Non-Target Arthropods

Spiromesifen and spirotetramat are compatible with most parasitoid species, lacewings and predatory bugs. However, high toxicity against predatory mites, predatory midges and lady beetle larvae has been documented.

Additional Notes for Optimal Deployment

Spirotetramat moves slowly in plant vascular tissues, and can take up to 2 weeks to yield reductions in pest populations. Use spirotetramat in early stages of pest infestation and on small plants to allow time for the active ingredient to be translocated to the entire plant.

Origin and History

Spiromesifen, a tetronic acid derivative, was discovered by Bayer Crop Science in the 1990s as synthetic derivatives of herbicidal protoporphyrinogen oxidase (PPO) chemistry. Spiromesifen products were initially registered in 2005 and are marketed by OHP (for nurseries and greenhouses) and Bayer Environmental Science (for landscapes). Parallel to the development of tetronic acid derivatives, Bayer Crop Science also developed and improved the efficacy of the tetramic acid derivatives. Spirotetramat is a tetramic acid derivative developed by Bayer Crop Science in the late 1990s, and introduced to the ornamentals industry by OHP in 2008.

Current Status

The spiromesifen products, Forbid and Judo, are registered for landscape and production (greenhouse and nursery) uses, respectively. Kontos (spirotetramat) is registered for uses in greenhouses, nurseries and interiorscapes.

GROUP 25 INSECTICIDE

GROUP MODE OF ACTION

Mitichondrial complex II electron transport inhibitors

IRAC CHEMICAL SUBGROUPS[1]

Beta-ketonitrile derivatives

General Group Profile

Cyflumetofen is a contact miticide with specific activity against spider mites. It helps manage all life stages of the spider mite, with rapid mortality of immature and adult spider mites appearing within hours. Mortality to spider mite eggs occurs within a few days.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

cyflumetofen

How the Chemistry Works Within the Pest

Similar to other insecticides and miticides that target the electron transport chain in the mitochondrial, cyflumetofen also interferes with energy production in the mitochondria. Different to Group 20, 21 and 24, cyflumetofen inhibits the normal function of the complex II of the electron transport chain. The end result is a failure of mitochondria to produce energy in the form of ATP.

How You Might Observe that Treatments are Working

Mites die when cellular metabolic energy reserves are depleted.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Cyflumetofen is highly effective against spider mites in various indoor and outdoor crop production systems.

Notes on Interactions with Non-Target Arthropods

Cyflumetofen is compatible with biological control agents including predatory mites, parasitoids, lady beetles and predatory bugs used in greenhouse production.

Additional Notes for Optimal Deployment

This is a contact miticide; therefore, thorough coverage of the canopy should be achieved through high volume spray and/or incorporation of a spreader-sticker.

Origin and History

Cyflumetofen is developed by Otsuka AgriTechno Co., Ltd. in Japan in early 2000s. The compound is launched commercially in 2007. BASF introduced cyflumetofen as a miticide to the ornamentals industry in the US in 2014.

Current Status

BASF introduced Sultan in 2014 for the management of spider mites in greenhouse, nursery, landscape and interiorscapes.

GROUP 28 INSECTICIDE

GROUP MODE OF ACTION

Ryanodine receptor modulators

IRAC CHEMICAL SUBGROUPS[1]

Diamides

General Group Profile

Although the diamides are systemic insecticides, their activity is much slower than some of the neonicotinoids. Therefore, it is a good idea to apply ryanodine receptor modulators upon early pest detection at treatment locations that present persistent episodes of population growth before infestations cause aesthetic or economic injury.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

chlorantraniliprole, cyantraniliprole

How the Chemistry Works Within the Pest

Chlorantraniliprole and cyantraniliprole target normal activities of muscle contractions. When a muscle fiber is contracted, two types of calcium channels are activated: voltage-gated channels that are activated by nerve impulses and ryanodine receptor channels that are activated by several types of neuronal proteins. When the calcium channels are activated, calcium ions flow into muscle fibers and stimulate contraction. Anthranilic diamides bind to the ryanodine receptors and cause the calcium channels to remain partially open, which results in excessive and uncontrollable calcium ion release into muscles that disrupts normal muscle function.

How You Might Observe that Treatments are Working

Treated insects twitch or go into spasm until death.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Target pests of chlorantraniliprole include caterpillars (turf and trees), white grubs, billbug and bluegrass weevil grubs, European crane fly larvae, clearwing borer larvae, birch leafminer, lace bugs, and suppression of chinch bugs in turf. Cyantraniliprole is registered for the management of sucking insects (aphids, lace bugs, soft scales and whiteflies), leaf-feeding beetles, caterpillars and thrips.

Notes on Interactions with Non-Target Arthropods

Chlorantraniliprole and cyantraniliprole are compatible with biological control agents, including predatory mites, parasitoids, lady beetles, minute pirate bugs and predatory mirids.

Additional Notes for Optimal Deployment

Products containing chlorantraniliprole can be applied as foliar spray, bark spray, soil drench, soil injection or broadcast granule. Soil drenches are effective against lace bugs and birch leafminers, while bark sprays to larval wound sites are recommended when managing feeding injury by clearwing borer larvae. Cyantraniliprole is currently labeled for applications through topical sprays and drenches of substrates and potting media.

Origin and History

Insecticidal properties of ryanodine, a water-soluble alkaloid produced by the South American plant *Ryania speciosa*, were first discovered in the 1940s by researchers from Rutgers University and Cornell University. The compound was used to control fruit moths, coddling moths, corn earworm, and European corn borer until registration of *Ryania*-containing products was voluntarily cancelled in 1997. DuPont developed chlorantraniliprole, a synthetic ryanodine receptor modulator, that was introduced to markets in 2008. Syngenta acquired the rights to chlorantraniliprole and another synthetic ryanodine analog, cyantraniliprole, in 2012. Cyantraniliprole was introduced in 2014.

Current Status

Acelepryn (chlorantraniliprole) is registered for uses in outdoor and interior landscapes, whereas Mainspring (cyantraniliprole) is registered for uses in greenhouse and interiorscapes.

GROUP 29 INSECTICIDE

GROUP MODE OF ACTION

Chorodontal organ modulators

IRAC CHEMICAL SUBGROUPS[1]

Flonicamid

General Group Profile

Flonicamid affects the nervous system associated with feeding behavior of sucking insects. Flonicamid has translaminar and systemic activities, however, the compound often binds tightly to organic matter in potting substrates and media. Once bound, the compound cannot be absorbed into plant tissues.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

flonicamid

How the Chemistry Works Within the Pest

Flonicamid works by interfering with the neurochemical processes that are associated with feeding. By interfering with nervous signals (through serotonin or chorodontal mechanoreceptors) that regulate fluid uptake by mouthparts, feeding behaviors of sucking insects are inhibited within hours.

How You Might Observe that Treatments are Working

Because flonicamid does not have direct insecticidal activity, these products do not kill sucking insects with quick knockdown. Exposed pests starve to death about 36-40 hours after application.

General Notes on Target Arthropods

This pest-specific insecticide is only effective against sucking insects, like aphids, whiteflies and mealybugs, and thrips.

Interactions with Non-Target Arthropods

Feeding blockers to homopteran pests results in low lethal or sub-lethal activity to predators and parasitoids used in biological control programs as well as limited ecotoxicity.

Origin and History

Discovery and development of flonicamid began in late 1990s by Ishihara Sangyo Kaisha, Ltd. of Osaka, Japan. FMC introduced flonicamid to the ornamental market in the US in 2005.

Current Status

Aria (flonicamid) is registered for sucking insect and thrips management in greenhouses.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

GROUP* *UNK* INSECTICIDE

** These are insecticides and miticides that have modes of action that are unknown or unclear, thus are not currently classified by IRAC and do not fit within a clearly delineated group.*

GROUP MODE OF ACTION

unknown

IRAC CHEMICAL SUBGROUPS[1]

Azadirachtin

General Group Profile

Azadirachtin and its analogues are botanical terpenoids extracted mainly from seed kernels, but also in smaller amounts from fruits, seeds, twigs, stem and bark of the neem tree (*Azadirachta indica*), which is a tropical evergreen native to arid regions of the Indian Subcontinent. Azadirachtin has slight systemic activity, is non-volatile, and is effective by contact or ingestion. Some product labels allow for soil drench, soil injection, trunk injection or chemigation. Antifeeding effects are expressed following ingestion by insects. When used as a systemic insecticide, azadirachtin is more effective against insects feeding on the foliage than other plant parts.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

azadirachtin

How the Chemistry Works Within the Pest

The actual mode of action of azadirachtin is unclear: neem tree compounds have displayed both antifeeding and growth disrupting properties against more than 200 insect species. However, the Insecticide Resistance Action Committee (IRAC) has not classified azadirachtin as either an antifeedant or an insect growth regulator. Once ingested, azadirachtin appears to turn on deterrent neuron(s) in susceptible insects that causes them to stop feeding on treated plants. Both ingestion and contact with azadirachtin induces growth or molting disruption in larvae and reproductive failure in adults. Larval growth inhibition is most likely caused by interference by azadirachtin with normal functioning of juvenile hormone or other growth hormones. Such growth inhibitory responses become stronger as treatment dosage increases. Even if the larvae survive a low dose of azadirachtin, fecundity may be subsequently reduced. Reproductive failure has also been reported for adult arthropods.

How You Might Observe that Treatments are Working

Larvae treated with azadirachtin often exhibit growth inhibition and malformation of body parts, which eventually leads to death. Adults, by contrast, suffer from weight loss and fail to produce mature eggs. Eggs treated with azadirachtin often fail to hatch.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Azadirachtin products are registered for the control of various species of adelgids, aphids, armored scales, grasshoppers, leaf feeding beetles and weevils, borers, caterpillars, flies, grubs, lacebugs, leafhoppers, leafminers, mealybugs, mites, mole crickets, psyllids, sawflies, soft scales, thrips, and whiteflies. Some products include plant parasitic nematodes as target pests.

Notes on Interactions with Non-Target Arthropods

Azadirachtin is readily degraded in the environment, leading to short residual longevity, and is nontoxic to mammals. In turn, this compound is a good alternative for natural or organic pest management. Most azadirachtin products are OMRI (Organic Materials Review Institute) -listed. Azadirachtin products are generally compatible with biological control agents. However, direct contact with insecticide solutions following topical applications can be detrimental to the survival of adult parasitoids and predatory bugs.

Additional Notes for Optimal Deployment

Products containing neem oil (or clarified, hydrophobic extract of neem oil) that are obtained *after* azadirachtin is extracted from the neem seed oil, do not contain sufficient azadirachtin to be considered an azadirachtin insecticidal product. Instead, neem oil should be used as plant-derived or horticultural oil.

Origin and History

Neem tree products have been used to cure or ameliorate many human ailments. Neem trees are often touted as the “village pharmacy” by subcontinental Indians as far back as 5,000 BC. A German scientist working in Sudan in 1959 observed that neem trees presented the only untouched green vegetation following a desert locust plague. British researchers J. Butterworth and E. Morgan were the first to demonstrate scientifically the antifeedant property of neem extracts (although the active ingredient was not identified at the time) on desert locusts in 1968. It was not until 1985, following the simultaneous report of the complete structure of azadirachtin by three different research groups. Currently, azadirachtin used for pest control is extracted mainly from neem seed kernels. A synthesis process has been developed by Professor Steven Ley of University of Cambridge and colleagues in 2007, which may increase the supply of azadirachtin.

Current Status

Insects that are repeatedly exposed to azadirachtin can become habituated and the antifeeding response can slowly become reduced. Insects can also overcome the antifeeding effect if azadirachtin is applied to their most preferred food plants. If habituation occurs, another non-azadirachtin product can be applied to extend the product efficacy.

GROUP* *UNK* INSECTICIDE

** These are insecticides and miticides that have modes of action that are unknown or unclear, thus are not currently classified by IRAC and do not fit within a clearly delineated group.*

GROUP MODE OF ACTION

unknown

IRAC CHEMICAL SUBGROUPS[1]

dicofol

General Group Profile

Dicofol has historically been considered an organochlorine compound, which is very similar to DDT, and is classified as a bridged diphenyl acaricide. One of the intermediate compounds in the steps to production of dicofol is DDT. Regardless, the mode of action of dicofol was never conclusively established. Dicofol has high mammalian toxicity and long persistence in the soil; therefore, its registration has been under intense scrutiny from regulators from around the world.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

dicofol

How the Chemistry Works Within the Pest

Despite its long history and use, the precise mode of action of dicofol remains unclear. Dicofol is suspected to inhibit enzyme activity and cause hyperactivity in the central nervous system.

How You Might Observe that Treatments are Working

Mites exposed to dicofol die very quickly.

General Notes on Target Arthropods

Dicofol was used as a general miticide in the ornamental industry.

Interactions with Non-Target Arthropods

Dicofol was considered incompatible with most biological control agents. Its use is strongly discouraged in any plant production and maintenance system where biological control is being practiced.

Origin and History

Dicofol is an old miticide, first marketed in the US by Rohm and Haas in the 1950s.

Current Status

EPA has canceled the registration of Kelthane. Existing stocks of any end-user products was allowed until 31 October 2016, after which all products are to be properly disposed.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

GROUP* *UNK* INSECTICIDE

** These are insecticides and miticides that have modes of action that are unknown or unclear, thus are not currently classified by IRAC and do not fit within a clearly delineated group.*

GROUP MODE OF ACTION

unknown

IRAC CHEMICAL SUBGROUPS[1]

Pyridalyl

General Group Profile

Pyridalyl is primarily effective via contact and by ingestion. Although some translaminar activity may occur, it is still important to achieve thorough coverage of the entire plant (through foliar spray or ultra-low volume fogging) for the best efficacy.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

pyridalyl

How the Chemistry Works Within the Pest

The mode of action of pyridalyl is currently unknown. Two potential modes of insecticidal activity have been proposed. Pyridalyl may selectively inhibit cellular protein synthesis. Alternatively, the metabolism of pyridalyl by cytochrome P450 may include creation of reactive oxygen forms that, then cause oxidative damage to cellular molecules and subsequent cell death.

How You Might Observe that Treatments are Working

Treated pests die within 3 days.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Pyridalyl targets thrips and caterpillars on greenhouse-grown ornamentals and non-bearing fruit and nut trees and vines.

Interactions with Non-Target Arthropods

Pyridalyl is compatible with predatory mites (*Amblyseius*, *Neosieulus*, *Phytoseiulus* and *Hypoaspis* spp.), ladybeetles, lace wings, parasitoids and minute pirate bugs, making this a valuable tool in developing an IPM program.

Additional Notes for Optimal Deployment

In situations where the resident thrips population is large, or when there is considerable migration of thrips into the greenhouse, reapplication with pyridalyl is recommended after between 14 and 21 days. No phytotoxicity from pyridalyl has been observed on impatiens, begonia, chrysanthemum, fuschia, geranium, marigold, New Guinea impatiens, pansy, petunia, Gerbera daisy, verbena and zinnia.

Origin and History

Dichloroallyl alcohol derivatives, which are the progenitor compounds to pyridalyl, have been reported since the 1980s to have insecticidal activity. Pyridalyl was first described in 2002 and developed by Sumimoto Chemical Co., Ltd. in Japan with the intent of discovering a new insecticide against caterpillar pests of cotton, vegetables and fruits that had developed resistance to existing insecticides (Sakamoto et al. 2005). Valent USA Corporation introduced the first product containing pyridalyl to US markets in 2008.

Current Status

IR-4 has funded several trials to investigate the efficacy of pyridalyl against various thrips species. Data suggested that pyridalyl achieved consistently good to excellent control of western flower thrips, good control of gladiolus thrips and chili thrips, but poor control of weeping fig thrips. Currently, Overture is registered for uses in greenhouse only. No product is labeled for outdoor or residential uses.

GROUP* *unclassified* INSECTICIDE

** These are insecticides and miticides that are not classified by IRAC, thus do not fit within a well-designated group.*

Group Type

Entomopathogenic fungi (EPF)

General Group Profile

There are several characteristics that make entomopathogenic fungi (EPF) particularly attractive for developers and users of microbial control products:

- More than 700 fungus species and strains from 90 genera are known to be pathogens of insects and mites. Each insect or mite species is afflicted by at least one fungus species or strain and each fungus could potentially be developed into a product. Experiments have been conducted on many species from the genera *Aschersonia, Agerata, Beauveria, Verticillium, Sphaerostilbe, Podonectria, Myriangium, Isaria* (= *Hirsutella* or *Paecilomyces*), and *Metarhizium.*
- Products containing EPF are usually formulated using dormant spores of the fungi and can be applied as foliar spray or soil drench using the same equipment as used for the other insecticides. Because of how these EPF products are applied, they are sometimes called biopesticides.
- The use of dormant spores as the main life stage for delivery also allows the fungi to survive for an extended time under adverse environmental conditions (e.g., sun and heat) following application.
- Most EPF products can be produced using fermentation process and at relative low cost.
- Some fungus species or strains have broad host spectrum; both sap sucking and chewing insects are susceptible to these broad-spectrum species or strains.

EPF products are compatible with most parasitoids and predators that attack pest insects and mites.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

Beauveria bassiana, Isaria formosorosea, Metarhizium anisopliae

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

How the Chemistry Works Within the Pest

Soon after a fungal spore in the spray solution lands on an insect's exoskeleton, the spore germinates and produces a hyphal tube that penetrates the cuticle. Penetration is aided by secreted enzymes that can dissolve the proteins, lipids, chitin and other components of the arthropod cuticle. Once the fungus penetrates into the hemocoel (i.e., the body cavity of arthropods), hyphae change in growth morphology into a yeast-like phase that circulates throughout the insect hemolymph. The fungus also produces toxins and secondary metabolites that kill the insect host. The fungus then reverts to the hyphal stage then produces spores that will result in infection of additional hosts.

How You Might Observe that Treatments are Working

Cadavers of infected insects often appear off-colored and powdery. When humidity is high, mycelium may grow from the cadaver.

General Notes on Target Arthropods

EPFs are generally broad-spectrum, with high effectiveness when used against soft-bodied insects.

Notes on Interactions with Non-Target Arthropods

EPFs are considered compatible to biological control agents and pollinators.

Additional Notes for Optimal Deployment

The EPF can be applied as foliar sprays and soil drench, with persistence slightly longer when applied to the soil. Regardless of the product used, avoid tank mixing with fungicides and prolonged storage in very high or low temperatures. EPF solutions should be used within 24 hours after mixing. Because the fungal spores will only germinate when in contact with insect cuticle, it is important to achieve complete coverage of the plant and soil during application. Temperature and humidity are crucial to the germination of the fungal spores. Most products work best between 60 degrees F to 80 degrees F and for at least 10-12 hours with relative humidity above 85 percent. EPF products are considered to have high levels of safety to crops, but it is always a good idea to test for potential phytotoxicity on a small number of plants before spraying the entire crop.

Origin and History

Beauveria bassiana occurs naturally in soils and is worldwide. This fungus species is also called white muscadine disease, named after the white sporulating structures that emerge from infected insects. This disease is named after the Italian entomologist Agostino Bassi, who in 1835 discovered this fungus species killing silkworms. Many strains of the fungus have been developed into commercial products. This fungus species has a wide host range, attacking mites and insects across nearly all orders. *Beauveria bassiana* is particularly effective against nymphs of sucking insects and larvae of beetles active on leaf surfaces and in the soil.

Metarhizium anisopliae is also a common soil fungal entomopathogen; it is commonly referred to as the green muscadine disease. Spores produced by *M. anisopliae* are at first white but soon turn green. More than 200 insect species are colonized by *M. anisopliae* and some species strains are extremely host specific. The generalist strain is typically used in the formulation of commercial products.

Isaria fumosorosea (formerly known as *Paecilomyces fumosoroseus*) is more closely associated with its insect host than either *B. bassiana* and *M. anisopliae* and *I. fumosorosea* is less commonly found in the soil. This fungus infects species in more than 25 insect families, as well as many species of mites

Current Status

Despite the many advantages and growing interest, EPF products remain a relatively small percentage of total insecticidal active ingredients used in turf and ornamental markets. In part, the small market share by EPF products may be related to slower knock down and mortality, with disease often developing 3-7 days after application. According to a survey by Faria and Wraight (2007, Biological Control 43: 237-256), 33.9 percent of microbial insecticides or miticides of the world contain *B. bassiana*, 33.9 percent contain *Metarhizium anisopliae*, 5.8 percent contain *Isaria fumosorosea*, 4.1 percent contain *Beauveria brongniartii*, 1.8 percent contain *Hirsutella thompsonii*, and 1.2 percent contain *Lecanicillium lecanii* (= *Verticillium lecanii*). In the US, only products containing *B. bassiana*, *I. fumosorosea* and *M. anisopliae* are available.

GROUP* *unclassified* INSECTICIDE

** These are insecticides and miticides that are not classified by IRAC, thus do not fit within a well-designated group.*

Group Type

Entomopathogenic nematodes (EN)

General Group Profile

Entomopathogenic nematodes (EN) are parasitic roundworms of insects. They are soft-bodied and unsegmented, and occur naturally in the soil. In the laboratory, ENs have been shown to attack a wide range of insects. However, in the field, the host range is narrower, depending on environmental conditions and ecological or behavioral barriers (such as the absence of susceptible hosts).

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

Most commercially available ENs belong to two nematode families:

Heterorhabditidae (*Heterorhabditis bacteriophora, H. megidis, H. indica* and *H. marelatus*), and;
Steinernematidae (*Steinernema glaseri, S. kraussei, S. carpocapsae, S. feltiae, S. riobrave,* and *S. scapterisci*)

How the Chemistry Works Within the Pest

The infective juvenile (or dauer) stage is the EN life stage responsible for attacking insects. ENs can be ambushers (i.e., those that lie in wait to attack any mobile insects that pass by), cruisers (i.e., those that active search for less mobile insects using volatiles and vibrations emitting from the insects), or can present a combination of both strategies. Infective juvenile nematodes enter an insect's body through direct openings (spiracles, mouth or anus) or intersegmental membranes on the cuticles. Once inside, ENs move into the hemocoel and release the symbiotic bacteria that are housed inside the ENs' bodies. The bacteria multiply and kill the infected insect. The ENs then feed on the insect tissues killed by the bacteria and continue their development into adulthood. Adult ENs reproduce and produce more infective juveniles, which are released into the environment.

How You Might Observe that Treatments are Working

ENs and their symbiotic bacteria often kill the infected insects very quickly. Insects killed by heterorhabditid nematodes turn red, whereas those killed by steinernematid nematodes turn brown or tan.

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[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

General Notes on Target Arthropods

Most commercially available EN species are host specific. *Steinernema kraussei* is registered for the management of black vine weevil larvae; *S. feltiae* for larvae of fungus gnats and shoreflies, and western flower thrips; *H. megidis* for weevils; and *H. indica* for fungus gnats and root mealybugs.

Interactions with Non-Target Arthropods

ENs are compatible with biological control agents commonly used against insect and mite pests of ornamental plants. Those biological agents released in the canopy are not in contact with the ENs applied to the soil or medium, and are therefore not impacted. The fast movement of soil-applied biological control agents also denies opportunity of infection by ENs. ENs are generally compatible with most pesticides used in pest management program. Users are advised to consult with the EN suppliers to determine the compatibility of ENs and other pesticides or fertilizer.

Additional Notes for Optimal Deployment

All products containing EN are formulated with fully active or semi-dormant infective juveniles. Therefore, different from other microbial or fungal products that are formulated with dormant stage, products containing EN should be purchased just before the application, stored properly and according to manufacturer instructions, and stored no longer than 3 months or exceeding the time limit indicated by the manufacturer. Before EN products are used, a small sample should be made and examined with microscopes or hand lens to verify the viability of the ENs (healthy juvenile stages will move around in the solution). Most ENs are host-specific; therefore, each EN product should be used against its intended pests. ENs are very sensitive to temperature and moisture level. Application should be made at temperature most suitable for the ENs and the treated areas should be kept wet for at least 8 hours and protected from direct exposure to sunlight and UV light. ENs can be applied with readily available application equipment or sprayers. Generally, filters in the sprayers should be removed and high pressure (greater than 300 psi) should be avoided. Large diameter nozzles and high volume (greater than 100 gallons per acre) are recommended. Check manufacturers' recommendations if ENs are to be tank mixed with other pesticides and fertilizer.

Origin and History

Steinernema glaseri was the first nematode to be utilized for pest management (against Japanese beetle grubs in the 1930s). In the 1970s and 1980s, the uses of *S. carpocapsae* achieved excellent control of soil-dwelling insects, but the uses of these ENs against foliage-feeding insects in the 1950s to 1980s failed and clearly demonstrated their weakness in adapting to foliage environment. The development of ENs for pest management has since focused on controlling soil-dwelling insect larvae.

Current Status

Several *Heterorhabditis* and *Steinernema* species are produced by the major biological control agent suppliers (such as BASF, Biobest, Bioworks, Koppert and Syngenta Bioline) for management of various immature soil-dwelling, boring or concealed insect pests.

GROUP* *unclassified* INSECTICIDE

** These are insecticides and miticides that are not classified by IRAC, thus do not fit within a well-designated group.*

Group Type

Entomopathogenic bacteria

General Group Profile

This section concerns entomophatogenic bacteria other than *Bacillus thuringiensis* (which was covered in Group 11).

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

Chromobacterium subtsugae

How the Chemistry Works Within the Pest

Chromobacterium subtsugae is a gram-negative beta-proteobacterium with a mode of action that is not well understood and likely very complex. The bacterium causes disease when a target pest ingests its spores. *Chromobacterium subtsugae* also produces bioactive metabolites or toxins during the stationary growth phase that have insecticidal activity. Inhibition of feeding, reduced egg hatch and reduced fecundity are all associated with infection.

How You Might Observe that Treatments are Working

Infected insects stop feeding soon after infection and die in a few days after feeding inhibition.

General Notes on Target Arthropods

Chromobacterium subtsugae is active against beetles, peach twig borer, caterpillars, aphids, azalea lace bugs, lygus bugs, mealybugs, whiteflies, thrips and mites.

Interactions with Non-Target Arthropods

Compatibility of *C. subtsugae* with non-target arthropods has not been well investigated. No adverse effects on honey bee survival and brood development are reported.

Origin and History

Bacteria as biopesticides of arthropods has focused largely on *Bacillus thuringiensis* since its commercialization in the 1920s (see Group 11). Parallel to development of *Bt* products, *Paenibacillus* (formerly *Bacillus*) *popilliae* was used to manage Japanese beetle grubs, with mixed results. Experimentation continues with other bacterial genera, like *Brevibacillus*, *Chromobacterium*, *Clostridium*, *Paenibacillus*, *Pseudomonas*, *Serratia*, *Xenorhabdus* and *Photorhabdus* (symbionts within entomophathogenic nematodes), and *Yersinia*.

Current Status

Grandevo PTO, containing *C. subtsugae*, is currently the only product registered for management of insects and mites on turfgrass and ornamental plants.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

GROUP* *unclassified* INSECTICIDE

** These are insecticides and miticides that are not classified by IRAC, thus do not fit within a well-designated group.*

Group Type

Horticultural oils

General Group Profile

Horticultural oils are a group of lightweight oils that are used for pest management. These products are applied as diluted spray onto the plant surface or the target pests' bodies. Horticultural oils are versatile and can be used in all situations. They are effective against many soft-bodied insects, have a short re-entry interval (REI) of 4 hours, and present very low risks to the environment, human, non-target organisms, and beneficial insects.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses

Different sources of horticultural oils are used as pesticides. An emulsifier is often added to most oil-based products to enable easy mixing with water or other pesticide solutions.

1) **Petroleum and mineral oils**: Summer/horticultural oil and dormant oil, with which we are most familiar, are refined petroleum products. Summer/horticultural oils are widely available and come in many different blends and trade names. Dormant oils are heavier and less refined petroleum oils that are effective against scale insects, aphids and mites on dormant plants and should be used after winter hardening and before bud breaks (watch your leaves fall off the trees if you used it after bud break). Horticultural (a.k.a. summer) oils can be used safely on foliage and flowers. Impurities, such as sulfur and other organic compounds, have been removed from the mineral oils and thus reduced the potential for phytotoxicity. These products are typically used at 1 or 2 percent dilution.
2) **Vegetable oils**: Products are formulated with refined or emulsified vegetable oil, such as cottonseed oil and soybean oil, and are often used as adjuvants with added pesticidal activity.
3) **Neem oil**: Neem oil is becoming more widely used in pest management, particularly in greenhouses. Neem oil products, such as Triact 70, are typically clarified hydrophobic extract of neem oil used at 0.5-2 percent dilution rate. Neem oil should not be confused with azadirachtin, although both are extracted from the neem seeds. Neem oil does not contain any azadirachtin (and thus does not provide insecticidal efficacy by the same action) and so should be used as a type of horticultural oil.
4) **Botanical or essential oils**: Some plant-derived essential oils, including citrus oil, peppermint oil and cedarwood oil, are promoted as organic pesticides. Due to reports of phytotoxicity across various use rates, some essential oils appear to work better as herbicides than insecticides. Research is needed to increase product quality, efficacy and safety.

How the Chemistry Works Within the Pest

Horticultural oils kill in several ways: 1) block the spiracles (air holes) of the insects, causing death by asphyxiation; 2) disrupt the integrity of insect and mite cuticle; 3) interfere with normal metabolism by interacting with fatty acids; and 4) disrupt normal feeding behaviors of aphids.

How You Might Observe that Treatments are Working

Contacted insects die quickly.

General Notes on Target Arthropods

Horticultural oils are effective against soft-bodied insects, particularly aphids, whiteflies, scale insects, adelgids, leafhoppers, spider mites and eriophyid mites.

Interactions with Non-Target Arthropods

Direct application and contact of horticultural oil can be detrimental to small, soft-bodied biological control agents (e.g., predatory mites). Avoid using horticultural oils when beneficial or desirable predatory insects are active. Once spray solutions have dried, horticultural oils provide no residual activity, and are then considered compatible with release of biological control agents and pollinators. Consequent to short residual activity, reapplication is typically needed within one or two weeks, particularly to control active or fast-reproducing pest arthropods.

Additional Notes for Optimal Deployment

Because horticultural oil solutions only work when contacted by the pest, complete canopy coverage is essential. This is particularly true for managing scale insects or spider mite eggs. Mixing with horticultural oil can enhance the efficacy of some insecticides and miticides. Under certain environmental conditions even the most refined mineral oil can cause phytotoxic problems to the plants. Horticultural oils can be used safely as long as temperatures do not exceed 90 degrees F or fall below freezing. Also avoid using horticultural oils when rain is expected, when plant tissues are wet, or when humidity exceeds 90 percent. High moisture and humidity levels will delay the evaporation of oil solution and can cause plant damage. Certain plant species, particularly conifers, redbuds and some maples, can be sensitive to horticultural oil sprays. Responses of other plant species may depend on the stress level of the plants. Crops suffering from drought-stress are more likely to be damaged.

Origin and History

Gardeners in the 18th century used kerosene to treat for insect infestation on crops. Although the kerosene application was quite effective, it was also very damaging or had high phytotoxicity to the plants that it was supposed to protect. In the mid-1900s, with improvements in refining technology, a new generation of petroleum-based oils or mineral oils was produced as pesticides. These petroleum oils were lightweight, had few impurities, and were lower in phytotoxicity when used as directed. Today, there are many commercially available petroleum- or plant-based horticultural oils.

Current Status

A large number of horticultural oil products are commercially available.

GROUP* *unclassified* INSECTICIDE

** These are insecticides and miticides that are not classified by IRAC, thus do not fit within a well-designated group.*

Chemical Class Type

Potassium salts of fatty acids

(= insecticidal soaps)

General Group Profile

Contact insecticide with limited to no residual activity.

Active Ingredients Labeled for Commercial Nursery, Greenhouse, Professional Landscape or Turfgrass Management Uses Potassium salts of fatty acids (insecticidal soaps)

How the Chemistry Works Within the Pest

The mode of action of insecticidal soaps is not fully understood. There are generally four hypotheses. First, insecticidal soaps may penetrate cuticle of insects and disrupt cell integrity, leading to cell leakage, cell collapse and eventually death. Insecticidal soaps also may cause death by blocking the spiracles (or breathing holes) of the insects and causing asphyxiation. Thirdly, by penetrating the cells, insecticidal soaps may act as an insect growth regulator by disrupting the normal functions of growth hormones and metamorphosis. And lastly, insecticidal soap molecules may penetrate deep into the mitochondria, disrupt the process of oxidative phosphorylation, and inhibit the normal process of energy production.

How You Might Observe that Treatments are Working

Contacted insects desiccate and die.

General Notes on Target Arthropods

Insecticidal soaps are inexpensive and effective against a large group of soft-bodied insects, including aphids, whiteflies, mealybugs, scale crawlers, thrips, two-spotted spider mites, and leafhoppers. For insecticidal soap solutions to be effective, target insects must be completely wetted by spray coverage. Efficacy is generally lower when insecticidal soaps are used to control older instars and larger, harder-bodied insects. Frequent reapplications may be needed, particularly if target pests are highly mobile or reintroduced to growing areas.

Notes on Interactions with Non-Target Arthropods

Insecticidal soap residues on plant surfaces degrade quickly and are almost non-toxic to organisms that come in contact with the residue once the spray solution has dried. Insecticidal soaps are generally considered safe to bees and natural enemies or compatible with biological control organisms. It is still prudent to avoid spraying directly on bees, lady beetles, predatory mites and other natural enemies.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

Additional Notes for Optimal Deployment

An additional benefit of insecticidal soaps is that they have greater efficacy at higher temperatures (+90 degrees F) and relative humidity (85 percent). This characteristic makes insecticidal soaps a good alternative to horticultural oils, which are not recommended for use when temperatures are above 85 degrees F. Some plant species are sensitive to phytotoxicity caused by insecticidal soaps, presenting leaf curling, distortion, discoloration, leaf drop, die-back and other conditions. Phytosensitive plant species include bleeding heart, crown of thorns, Easter lily, gardenia, hawthorn, horse chestnut, Japanese maple, lantana, maidenhair fern, mountain ash, nasturtium, Prunus (cherries, plum), portulaca, sweet pea, and some tomato cultivars. Azalea, begonia, fuchsia, geranium and impatiens are moderately sensitive. The severity of phytotoxic responses in plants may vary among species and cultivars and is condition dependent. Phytotoxicity, particularly for conifers, appears to be more severe during a drought or if the plants are under drought stress. Herbaceous plant species or soft vegetative tissues are more susceptible to phytotoxicity than woody species or tissues. Larger and older plants are more tolerant than young, succulent plants. Insecticidal soap solution of a higher rate also has a higher potential for causing phytotoxicity. Test for phytotoxicity to insecticidal soaps by spraying on a few plants of each species and observing for at least 24 hours to determine if any phytotoxic reactions occur before applying the same solution to the entire crop or planting.

Origin and History

Similar to the use of kerosene, the use of soaps for pest management begin as early as the 18th century. However, because of a high content of impurities and caustic nature of the remaining alkali, a high level of phytotoxicity was often observed. It was not until 1947 that the first safe insecticidal soap was registered for use.

Current Status

A large number of insecticidal soap products are commercially available for uses on ornamental plants.

[1] http://www.irac-online.org/modes-of-action. Mention of trade names does not imply approval, endorsement, or guarantee of the products.

For additional information, contact your county Extension office, or:

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