Insecticides Used in the Urban Environment: Mode of Action[1]

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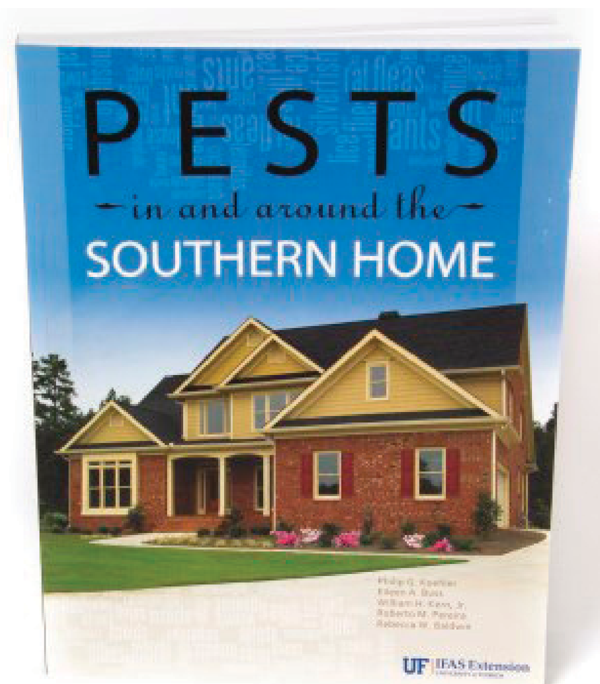

This fact sheet is excerpted from SP486: *Pests in and around the Southern Home*, which is available from the UF/IFAS Extension Bookstore. http://ifasbooks.ifas.ufl.edu/p-1222-pests-in-and-around-the-southern-home.aspx
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Most people know that insecticides kill insects. However, the way in which these chemicals work is a mystery to most of us. How an insecticide works is called its mode of action. A complete understanding of the mode of action of an insecticide requires knowledge of how it affects a specific target site within an organism. The target site is usually a critical protein or enzyme in the insect, but some insecticides affect broader targets. For example, silica aerogels affect the entire lipid layer on the insect cuticle. Although most insecticides have multiple biological effects, toxicity is usually attributed to a single major effect. This fact sheet is intended to explain what insecticides do in insects to cause toxicity and death (Table 1).

Insecticides can be classified according to their mode of entry into the insect as 1) stomach poisons, 2) contact poisons, or 3) fumigants. However, many insecticides belong to more than one category when grouped in this way, limiting its usefulness. Another way insecticides can be classified is by their mode of action. Most insecticides affect one of five biological systems in insects. These include: 1) the nervous system, 2) the production of energy, 3) the production of cuticle, 4) the endocrine system, and 5) water balance. This method of classification is preferred among scientists.

Insecticides that Affect the Nervous System

Most traditional insecticides fit into this category. Pyrethroid, organophosphorus, and carbamate insecticides all adversely affect the nervous system.

Pyrethroids are synthetic chemicals whose structures mimic the natural insecticide pyrethrin. Pyrethrins are

1. This document is ENY282, one of a series of the Entomology and Nematology Department, UF/IFAS Extension. Original publication date September 1997. Revised July 2011 and February 2022. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

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found in the flower heads of plants belonging to the family Compositae (e.g., chrysanthemums). These insecticides have a unique ability to knock down insects quickly. Synthetic pyrethrins (also known as pyrethroids) have been chemically altered to make them more stable Pyrethroids are axonic poisons (they poison the nerve fiber). They bind to a protein in nerves called the voltage-gated sodium channel. Normally, this protein opens causing stimulation of the nerve and closes to terminate the nerve signal. Pyrethroids bind to this gate and prevent it from closing normally which results in continuous nerve stimulation. This explains the tremors exhibited by poisoned insects. They lose control of their nervous system and are unable to produce coordinated movement.

Carbamate and organophosphorus insecticides also affect the nervous system. However, these insecticides are synaptic poisons. The synapse is a junction between two nerves or a nerve connection point (hence the name synaptic poison). Specifically, organophosphorus and carbamate insecticides bind to an enzyme found in the synapse called acetylcholinesterase. This enzyme is designed to stop a nerve impulse after it has crossed the synapse. Organophosphorus and carbamate insecticides bind to and prevent the enzyme from working. Therefore, poisoned synapses cannot stop the nerve impulse. Consequently, continued stimulation of the nerve occurs as observed with pyrethroids. Again, poisoned insects exhibit tremors and uncoordinated movement.

Avermectins belong to a group of chemicals called macrolactones. These chemicals are derived from a fungus and also adversely affect the nervous system. Avermectins are axonic poisons (affect the nerve fiber). They bind to another protein in the nerve fiber called the (gamma) amino butyric acid (GABA)-gated chloride channel. This protein forms a channel within the nerve that attenuates some nerve impulses. Avermectins block the channel causing nerve hyperexcitation. Again, the result is that the nervous system becomes overexcited resulting in tremors and uncoordinated movement.

Two new insecticides have been introduced late in the 1990s that also cause toxicity by affecting the nervous system. Imidacloprid belongs to the chloronicotinyl chemical class of insecticides. Imidacloprid is also a synaptic nervous system poison. Specifically, this chemical mimics the action of a neurotransmitter called acetylcholine. Acetylcholine normally turns on a nerve impulse at the synapse but its effects are terminated very quickly. Imidacloprid turns on the nerve impulse but cannot terminate it because of its chemical structure. Therefore, the nervous system is overexcited (as with organophosphates, carbamates, and pyrethroids), resulting in tremors and uncoordinated movement. Imidacloprid is more specific for insect nervous tissue compared with mammalian nervous tissue.

The other insecticide introducded late in the 1980s that affects the nervous system is fipronil. Fipronil is a phenylpyrazole chemical class insecticide. Its mode of action is similar to cyclodiene insecticides (e.g. chlordane or aldrin), which were used extensively as termiticides during the 1960's and 1970's, and the abamectins described above. These chemicals are axonic poisons that affect the GABA-gated chloride channel.

Insecticides that Inhibit Energy Production

Only a handful of chemicals that inhibit the production of energy are currently in use as insecticides. However, significant research and development of new chemicals with this mode of action are currently under way by many pesticide manufacturers.

The most pervasive and well-known energy inhibiting insecticide is hydramethylnon, the active ingredient in Amdro®, Siege Gel Bait®, and Combat®. This insecticide belongs to the chemical class amidinohydrazone. This chemical binds to a protein called a cytochrome in the electron transport system of the mitochondrion. This binding blocks the production of ATP. Insects killed by these chemicals die on their feet. They essentially "run out of gas."

Another insecticide currently available that inhibits energy production is sulfluramid. This insecticide belongs to the halogenated alkyl sulphonamide chemical class. It is the active ingredient found in Raid Max® ant bait. Sulfluramid is made more toxic by the organism. The parent chemical is converted to toxic metabolites by enzymes in the body.

Finally, the fumigant sulfluryl fluoride inhibits energy production. This chemical is very volatile and typically used to fumigate houses for drywood termite infestations. Sulfluryl fluoride is fast-acting and its mode of action is similar to hydramethylnon and sulfluramid. However, the enzyme affected is different.

Many new chemicals are being developed for use as energy production inhibitors. Chemicals in the class pyrrole, thiourea, and quinazoline are showing great promise as pesticides that inhibit energy production.

Insecticides that Affect the Insect Endocrine System

These chemicals are typically referred to as insect growth regulators, or IGRs. IGRs act on the endocrine or hormone system of insects. These insecticides are specific for insects, have very low mammalian toxicity, are nonpersistent in the environment, and cause death slowly. Most of the currently registered IGRs mimic the juvenile hormone produced in the insect brain. Juvenile hormone tells the insect to remain in the immature state. When sufficient growth has occurred, the juvenile hormone production ceases triggering the molt to the adult stage. IGR chemicals, such as hydroprene, methoprene, pyriproxyfen, and fenoxycarb, mimic the action of juvenile hormone and keep the insect in the immature state. Insects treated with these chemicals are unable to molt successfully to the adult stage and cannot reproduce normally.

Insecticides that Inhibit Cuticle Production

These chemicals are known as chitin synthesis inhibitors or CSIs. They are often grouped with the IGRs. The most notable chemical being used as a CSI is the benzoyphenyl ureas. This class of insecticides includes lufenuron (Program®) which is a systemic insecticide used for flea control (fed to your pet), diflubenzuron (Dimilin®) used against fly larvae in manure, and hexaflumuron (Sentricon®) used in a termite bait station. These chemicals inhibit the production of chitin. Chitin is a major component of the insect exoskeleton. Insects poisoned with CSIs are unable to synthesize new cuticle, thereby preventing them from molting successfully to the next stage.

Insecticides Affecting Water Balance

Insecticides with this mode of action include boric acid, diatomaceous earth, and sorptive dusts. Insects have a thin covering of wax on their body that helps to prevent water loss from the cuticular surface. Silica aerogels (sorptive dusts) and diatomaceous earth are very effective at absorbing oils. Therefore, when an insect contacts one of these chemicals it absorbs the protective waxy covering on the insect resulting in rapid water loss from the cuticle and eventually death from dessication. Unfortunately, insects that live in environments with high relative humidity, or that have ready access to a water source, show an increased tolerance to silica aerogels and diatomaceous earth. This is because water loss can be minimized by either of these conditions, and the insect may survive despite the absence of a wax layer.

Borate-containing insecticides also disrupt water balance in insects. The exact mode of action (more specifically the target site) of borate containing insecticides is not currently known.

Table 1. Examples of commonly used insecticides and their mode of action.

Insecticide Class	Common Name	Example (Trade Name)	Primary Site Affected
Pyrethroid	Permethrin	Flee	Nervous System
Carbamate	Propoxur	Baygon	Nervous System
Organophosphorus	Chlorpyrifos	Dursban	Nervous System
Avermectins	Abamectin	Avert	Nervous System
Chloronicotinyl	Imidacloprid	Advantage	Nervous System
Cyclodiene	Aldrin	*	Nervous System
Amidinohydrazone	Hydramethylnon	Amdro	Energy Production
Sulphonamide	Sulfluramid	Raid Max	Energy Production
Fumigant (Inorganic)	Sulfluryl Fluoride	Vikane	Energy Production
Juvenile Hormone Analog	Hydroprene	Gencor	Endocrine System
Juvenile Hormone Analog	Methoprene	Pharoid	Endocrine System
Juvenile Hormone Mimic	Fenoxycarb	Logic	Endocrine System
Juvenile Hormone Mimic	Pyriproxyfen	Archer	Endocrine System
Benzoylphenyl Urea	Diflubenzuron	Dimilin	Chitin Production
Benzoylphenyl Urea	Lufenuron	Program	Chitin Production
Benzoylphenyl Urea	Hexaflumuron	Sentricon	Chitin Production
Inorganic	Borates	Roach Prufe	Water Balance
Inorganic	Silica Aerogels	Dri-Die	Water Balance
Inorganic	Diatomaceous Earth	Shell Shock	Water Balance

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