

Pesticide Resistance and Resistance Management¹

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Populations of animals, fungi, bacteria, and plants possess the ability to respond to sustained changes or stresses in their environment in ways that enable the continued survival of the species. Such environmental stresses include physical factors (e.g., temperature or humidity), biological factors (e.g., predators, parasites, or pathogens) and environmental contaminants. In any population, a small percentage of individuals will be better able to respond to new stresses because of unique traits or characteristics that they possess. Consequently, those individuals will survive, reproduce, and become more common in a population. This phenomenon is commonly referred to as “survival of the fittest.”

Many pest species, such as the citrus rust mite, are exceptionally well-equipped to respond to environmental stresses because of their short generation time and large reproductive potential. The use of chemical sprays to control insect, mite, and fungal diseases of citrus creates a potent environmental stress. There are now many examples of pests and pathogens that have responded by developing resistance to one or more pesticides. Pesticide-resistant individuals are those that have developed the ability to tolerate doses of a toxicant that would be lethal to the majority of individuals. The resistance mechanisms can vary according to pest species and/or the class of chemical to which the pest is exposed. Resistance mechanisms include an increased capacity to detoxify the pesticide once it has entered the pest’s body, a decreased sensitivity of the target site that the pesticide acts upon, a decreased penetration of the pesticide through the cuticle, or sequestration of the pesticide within the organism. The main resistance mechanism for pathogens is a change in the target site so that the pathogen is less susceptible or fully resistant. A single resistance mechanism can sometimes provide defense against different classes of chemicals and this is known as *cross-resistance*. When more than one resistance

mechanism is expressed in the same individual, this individual is said to show *multiple resistance*.

Because the traits for resistance are passed from one generation to the next, continued stress from a pesticide may, over time, create resistance in the majority of individuals in a population. From an operational perspective, this process would be expressed as a gradual decrease and eventual loss of effectiveness of a chemical. Resistance to a particular chemical may be stable or unstable. When resistance is stable, the pest population does not revert to a susceptible state even if the use of that chemical is discontinued. When resistance is unstable and use of the chemical is temporarily discontinued, the population will eventually return to a susceptible state, at which time the chemical in question could again be used to manage that pest. However, in this situation, previously resistant populations may eventually show resistance again.

Of the factors that affect the development of resistance, which include the pest’s or pathogen’s biology, ecology and genetics, only the operational factors can be manipulated by the grower. The key operational factor that will delay the onset of pesticidal resistance and prolong the effective life of a compound is to assure the survival of some susceptible individuals to dilute the population of resistant individuals. The following operational procedures should be on a grower’s checklist to steward sound pesticidal resistance management for acaricides, insecticides, fungicides, and herbicides:

1. Never rely on a single pesticide class.
2. Integrate chemical control with effective, complementary cultural and biological control practices.
3. Always use pesticides at recommended rates and strive for thorough coverage.

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The use of trade names in this publication is solely for the purpose of providing specific information. UF/IFAS does not guarantee or warranty the products named, and references to them in this publication does not signify our approval to the exclusion of other products of suitable composition. Use pesticides safely. Read and follow directions on the manufacturer’s label.

4. When there is more than one generation of pest, alternate different pesticide classes.
5. Do not use tank mixtures of products that have the same mode of action.
6. If control with a pesticide fails, do not re-treat with a chemical that has the same mode of action.

Reports of resistance have been documented for certain acaricides used to control citrus rust mite and fungicides used to combat diseases in Florida. Resistance to Benlate developed in the greasy spot fungus shortly after the product was introduced about 30 years ago and is still widespread. Benlate resistance also occurs in the scab fungus in isolated situations and is stable. Resistance has been detected in tangerine groves with Alternaria brown spot to strobilurin fungicides (Abound, Gem, and Headline and contained in the mixtures Pristine and Quadris Top) but no resistance has developed to ferbam. Dicofol resistance in citrus rust mite was detected throughout the citrus industry about 10 years ago, but resistance proved to be unstable and usage of dicofol has continued. Agri-mek tolerance in citrus rust mite is of concern and growers should follow sound resistant management practices when using this product.

The following tables are provided to aid in the rotation of pesticides with different modes of action within a season or from year to year. There is a separate table for insecticides/acaricid-

es, fungicides, and herbicides. The information in these tables was derived from information produced by the Insecticide Resistance Action Committee (IRAC) (<http://www.irac-online.org/>), Fungicide Resistance Action Committee (FRAC) (<http://www.frac.info/>) and the Herbicide Resistance Action Committee (HRAC) (<http://hracglobal.com/pages/classificationofherbicidesiteofaction.aspx>). Each table lists the number (or letter in the case of herbicides) of the group code for each pesticide class, the group name or general description of that group of pesticides, the common name of pesticides used in citrus production that belong to each group and examples of trade names of pesticides for each common name listed. When using the table to rotate between using products with different modes of action, choose products with a different group code than previously used in the grove during the current growing season. In the case of insecticides/acaricides, many of these pesticides are broken into subgroups. It is unclear whether cross resistance will occur between these subgroups. When possible, it is recommended to rotate with an entirely different group. (Note: The IRAC and FRAC mode of action systems both use a similar numbering system. There is no cross resistance potential between the insecticides and fungicides.) Products with broad-based activity such as sulfur, copper, and oil are not included in this list because the development of resistance to them is not likely.

TABLE 1. Insecticides and miticides used in Florida citrus grouped by mode of action.

IRAC Group ¹	Subgroup	Group Name	Common Name	Trade Name
1	1A	Carbamates	Aldicarb Carbaryl Oxamyl	Temik Sevin Vydate
1	1B	Organophosphates	Acephate Chlorpyrifos Dimethoate Fenamiphos Malathion Methidathion Naled Phosmet	Orthene Lorsban Dimethoate Nemacur Malathion Supracide Dibrom Imidan
2		Cyclodiene Organochlorines	Endosulfan	Phaser
3		Pyrethroids	Bifenthrin Fenpropathrin Zeta-Cypermethrin	Brigade Danitol Mustang
4	4A	Neonicotinoids	Acetamiprid Clothianidin Imidacloprid Thiamethoxam	Actara, Assail, Admire Pro, Advise, Alias, Belay, Couraze, Imida E-Ag, Impulse, Macho, Montana, Nuprid, Pasada, Platinum, Prey, Torrent, Widow
	4D	Butenolides	Flupyradifurone	Sivanto
5		Spinosyns	Spinosad Spinetoram	Spintor Delegate
6		Avermectins	Abamectin	Abacus, Abba, Agri-mek, Clinch, Epi-mek, Reaper, Zoro
7	7A	Juvenile Hormone Analogues	Methoprene	Extinguish Ant Bait
	7B	Fenoxycarb	Fenoxycarb	Precision
	7C	Pyriproxyfen	Pyriproxyfen	Knack
10		Hexythiazox	Hexythiazox	Savey
11		<i>Bacillus thuringiensis</i> (B.t.)	B.t. var. aizawai B.t. var. kurstaki	Various Various
12	12B	Organotin miticides	Fenbutatin oxide	Vendex
	12C	Propargite	Propargite	Comite
15		Benzoylureas	Diflubenzuron	Micromite
16		Buprofezin	Buprofezin	Applaud
18		Diacylhydrazines	Methoxyfenozide	Intrepid
21		METI acaricides	Pyridaben Fenpyroximate	Nexter Portal
23		Tetronic/Tetramic acid derivatives	Spirodiclofen Spirotetramat	Envidor Movento
28		Diamides	Chlorantraniliprole	Exirel, Verimark, Voliam Flexi (one component)
UN		Unknown MOA	Bifenazate	Acramite
			Cryolite	Kryocide
			Dicofol	Kelthane

¹Mode of action based on the Insecticide Resistance Action Committee (IRAC) Mode of Action Classification V7.3 (2014).

TABLE 2. Fungicides used in Florida citrus grouped by mode of action.

FRAC Group ¹	Group Name	Common Name	Trade Name
1	MBC - fungicides	thiabendazole	Many (TBZ)
3	DMI - fungicides	difenoconazole fenbuconazole imazalil propiconazole	Quadris Top Enable Many Banner Maxx, Bumper, Orbit, Propimax
4	PA - fungicides	metalaxyl mefenoxam	Ridomil Ultraflourish, Ridomil Gold, Subdue
7	SDHI – fungicides	Boscalid fluopyram fluxapyroxad	Pristine Luna Sensation Priaxor Xemium
11	QoI - fungicides	azoxystrobin trifloxystrobin pyraclostrobin	Abound, Graduate A+, Quadris Top Gem Headline Pristine
12	PP - fungicides	fludioxonil	Graduate Graduate A+
33	Phosphonates	Fosetyl-Al Phosphorous acid	Aliette Phostrol, ProPhyt
40	CAA - fungicide	mandipropamid	Revus
43	Benzamides	Fluopicolide	Adorn
M3	dithio-carbamates	ferbam	Ferbam Granuflo
M1	Inorganic	copper	Many

¹Mode of action based on the Fungicide Resistance Action Committee (FRAC) 2015.

TABLE 3. Herbicides used in Florida citrus grouped by mode of action.

HRAC Group ¹	Group Name	Common Name	Trade Name
A	FOPs DIMs	fluzifop-p-butyl clethodim sethoxydim	Fusilade Prism, Select, Volunteer Poast
C1	Triazine Uracil	simazine bromacil	Princep, Sim-Trol Hyvar, Krovar
C2	Urea	diuron	Direx, Karmex, Krovar
D	Bipyridylum	diquat paraquat	Reglone-Dessicant Gramoxone
E	Diphenylether N-phenylphthalimide Triazolinone	oxyfluorfen flumioxazin carfentrazone-ethyl	Galigan, Goal, Oxiflo Chateau, Suregard Aim
F1	Pyridazinone	norflurazon	Solicam
G	Glycine	glyphosate	Many (Roundup)
K1	Dinitroaniline Pyridine	oryzalin pendimethalin trifluralin thiazopyr	Surflan, Oryza Pendulum, Prowl Treflan, Snapshot Mandate
L	Benzamide	isoxaben	Gallery, Snapshot
N	Thiocarbamate	EPTC	Eptam
Z	Organoarsenical	MSMA	MSMA-6

¹Mode of action of herbicides based on the Herbicide Resistance Action Committee (HRAC) 2005.