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# 2019–2020 Florida Citrus Production Guide: Pesticide Resistance and Resistance Management[1]

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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, bacterial and fungal diseases, and weeds of citrus creates a potent environmental stress. There are now many examples of pests, pathogens, and weeds 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 fungal pathogens is a change in the target site so that the pathogen is less susceptible or fully resistant. With repeated or intense exposure to herbicides, some weeds develop resistance because only individuals that are capable of detoxifying the chemical persist over time. A single resistance mechanism can sometimes provide defense against different classes of chemicals; 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*.

Of the factors that affect the development of resistance, including 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 assuring the survival of some susceptible

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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 and complementary cultural and biological control practices.

3. Always use pesticides at recommended rates and strive for thorough coverage.

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 is also likely to be found in weeds with repeated exposure to certain herbicides. 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. In tangerine groves with Alternaria brown spot, resistance has been detected to strobilurin fungicides (Abound, Gem, and Headline and contained in the mixtures Pristine, Priaxor, and Amistar 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 resistance management practices when using this product. Recent studies have shown reduced susceptibility to several insecticides in populations of Asian citrus psyllid after repeated exposure to similar materials, but that susceptibility can be restored by rotating modes of action used in management programs. Resistance management is crucial to the management of this insect. Glyphosate-resistant weeds are becoming commonplace in many production systems with the repeated use of this popular pre-emergence herbicide, highlighting the need to rotate materials for weed management.

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 are separate tables for insecticides/acaricides, 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 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 | carbaryl oxamyl | Sevin<br>Vydate |
| 1 | 1B | Organophosphates | acephate<br>chlorpyrifos<br>dimethoate<br>malathion<br>methidathion<br>naled<br>phosmet | Orthene<br>Lorsban<br>Dimethoate<br>Malathion<br>Supracide<br>Dibrom<br>Imidan |
| 2 | 2A | Cyclodiene Organochlorines | endosulfan | Phaser |
| 3 | 3A | Pyrethroids | bifenthrin<br>fenpropathrin<br>zeta-cypermethrin | Brigade<br>Danitol<br>Mustang |
| 4 | 4A | Neonicotinoids | acetamiprid<br>clothianidin<br>imidacloprid<br>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<br>spinetoram | Spintor<br>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 | 10A | Hexythiazox | hexythiazox | Savey |
| 11 | 11A | *Bacillus thuringiensis* (B.t.) | B.t. var. aizawai<br>B.t. var. kurstaki | Various<br>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 | 21A | METI acaricides | pyridaben<br>fenpyroximate | Nexter<br>Portal |
| 23 | | Tetronic/Tetramic acid derivatives | spirodiclofen<br>spirotetramat | Envidor<br>Movento |
| 28 | | Diamides | chlorantraniliprole | Exirel, Verimark, Voliam Flexi (one component) |
| UN | | Unknown MOA | bifenazate | Acramite |
| | | | cryolite | Kryocide |
| | | | dicofol | Kelthane |

[1] Mode of action based on the Insecticide Resistance Action Committee (IRAC) Mode of Action Classification V8.4 (2018).

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

| FRAC Group[1] | Group Name | Common Name | Trade Name |
|---|---|---|---|
| 1 | MBC—fungicides (Methyl benzimidazole carbamates) | thiabendazole | Many (TBZ) |
| 3 | DMI—fungicides (Demethylation inhibitors) | difenoconazole<br>fenbuconazole<br>imazalil propiconazole | Amistar Top<br>Enable<br>Many<br>Banner Maxx, Bumper, Orbit, Propimax |
| 4 | PA—fungicides (Phenylamides) | metalaxyl<br>mefenoxam | Ridomil<br>Ultraflourish, Ridomil Gold, Subdue |
| 7 | SDHI—fungicides (Succinate-dehydrogenase inhibitors) | boscalid<br>fluopyram<br>fluxapyroxad | Pristine<br>Luna Sensation Priaxor Xemium |
| 11 | QoI—fungicides (Quinone outside inhibitors) | azoxystrobin<br>trifloxystrobin<br>pyraclostrobin | Abound, Graduate A+, Amistar Top<br>Gem<br>Headline, Pristine |
| 12 | PP—fungicides (Phenylpyrroles) | fludioxonil | Graduate, Graduate A+ |
| 40 | CAA—fungicide (Carboxylic acid amides) | mandipropamid | Revus |
| 43 | Benzamides | Fluopicolide | Adorn, Presidio |
| M03 | Dithiocarbamates | ferbam | Ferbam Granuflo |
| M01 | Inorganic | copper | Many |
| P07 | Phosphonates | fosetyl-Al<br>phosphorous acid and salts | Aliette<br>Phostrol, ProPhyt |

[1] Mode of action based on the 2018 Fungicide Resistance Action Committee (FRAC) Mode of Action Classification

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

| HRAC Group[1] | Group Name | Common Name | Trade Name |
|---|---|---|---|
| A | Aryloxyphenoxy-propionate<br>Cyclohexanedione | fluazifop-p-butyl<br>sethoxydim | Fusilade<br>Poast |
| C1 | Triazine<br>Uracil | simazine<br>bromacil | Caliber, Princep, Simazine, Hyvar, Krovar |
| C2 | Urea | diuron | Direx, Karmex, Krovar |
| D | Bipyridylium | paraquat | Gramoxone |
| E | N-phenylphthalimide Triazolinone<br>Pyrimidinedione | flumioxazin<br>carfentrazone-ethyl<br>saflufenacil | Chateau,<br>Aim<br>Treevix |
| F1 | Pyridazinone | norflurazon | Solicam |
| F2 | Triketone | mesotrione | Broadworks |
| G | Glycine | glyphosate | (Various) E.g., Roundup, Gly Star |
| K1 | Dinitroaniline | oryzalin<br>pendimethalin | Surflan<br>Prowl |
| L | Alkylazine | indaziflam | Alion |

[1] Mode of action based on the 2018 Herbicide Resistance Action Committee (HRAC) Mode of Action Classification