



Fungicide Resistance Action Committee's (FRAC) Classification Scheme of Fungicides According to Mode of Action¹

Frederick M. Fishel²

This guide addresses resistance to pesticides and describes the Fungicide Resistance Action Committee's (FRAC) classification of fungicides and bactericides registered for use in Florida by their modes of action. A cross reference of active ingredient common names with corresponding examples of their trade names is also provided.

Fungicide-resistant plant pathogens are not new. Although the first fungicide resistance confirmation was in 1960, there were few subsequent incidences up until 1970. Since then, there have been more incidences, especially with the introduction of systemic fungicides. Also of concern has been the amount of time taken for resistance to emerge; sometimes within two years of a new commercial fungicide introduction. Fungicide resistance is not unique. Insecticide-resistant insects, herbicide-resistant weeds and antibiotic-resistant bacteria are well documented. These pests have two common traits: they have exceptionally large populations with a rapid rate of reproduction. Weeds were the last category of pests to show resistance

because they only reproduce, at most, once per year. Insects reproduce with multiple generations in a single year; some bacteria and fungi reproduce several times in a single hour. Where large populations exist, great genetic diversity exists within the population. Within these populations, there will be several individuals that are tolerant of chemical control measures, perhaps only one in a million or billion. Pests typically become resistant when the same pesticide is used repeatedly within a single year or for several consecutive years. Some researchers believe selection pressure forces pests to mutate. However, there are more likely reasons for resistance:

- There were always a few of the resistant types present.
- When the pesticide is applied, the susceptible types are controlled, and then the smaller, resistant populations increase and re-infest the site.

1. This document is PI-94, one of a series of the Pesticide Information Office, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date January 2006. Visit the EDIS Web Site at <http://edis.ifas.ufl.edu>.

2. Frederick M. Fishel, associate professor, Agronomy Department, and Director, Pesticide Information Office; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

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Cross Resistance versus Multiple Resistance

More than 50 different fungicide active ingredients and many more trade products, including mixtures, are available to agricultural producers in Florida today. Many of these active ingredients work in the same way; in other words, they have the same *mode of action*. Although there are numerous trade products available at the current time, there are fewer than 20 growth mechanisms affected by these fungicides. When a certain plant pathogen is not controlled by fungicides affecting the same growth process, it is said to be cross-resistant. An example of a plant pathogen that has cross resistance is one that is resistant to fungicides in the chemical groups, triazoles and pyrimidines, both which are demethylation inhibitors which disrupt sterol synthesis. A more serious concern is multiple resistance. This is a phenomenon that occurs when a plant pathogen is not controlled by fungicides which affect different plant-growth processes. For example, a plant pathogen that is resistant to fungicides which inhibit both mitosis and protein synthesis, two differing fungal growth processes, would be labeled as a plant pathogen having multiple resistance.

Fungicide Selection

Farmers and crop advisors need to know which fungicides are best suited to combat resistant plant pathogens. To support the use of fungicides suitable for resistance management, the FRAC numerical classification of fungicides in Table 1 is used on fungicide labeling by some manufacturers. The fungicides are classified according to their modes of action, collective and chemical group names, and active ingredient common names. Some examples of popular trade names are provided in Table 2 as a cross reference. The tables do not include all fungicides that are registered for use globally or in the U.S.; rather, those available only in Florida. Those which have an intrinsic "high risk" of resistance evolution are identified. "High risk" is determined by the following indicators:

- Laboratory studies have shown resistant mutants within the population;
- The active ingredient is known for the practice of repetitive use or sustained treatments;
- The active ingredient is known to have an extensive area of use; and,
- The target plant pathogens are known to have large populations with rapid multiplication.

The system is encouraged by FRAC for fungicide registrants to indicate the mode of action group in a uniform location on their product labels; some registrants currently identify the group on the front panel of their product labels. Similar systems have been proposed and encouraged for herbicides and insecticides. Because of the great variety of trade names and package mixtures of fungicides, it is difficult for agricultural producers to keep track of which modes of action they use.

Additional Information

Fungicide Resistance Action Committee (FRAC): <http://www.frac.info/>

McCoy, C.W., M.E. Rogers, and L.W. Timmer. 2004. 2005 Florida citrus pest management guide: pesticide resistance and resistance management. UF/IFAS EDIS Document ENY-624. <http://edis.ifas.ufl.edu/CG026>.

Tomlin, C.D.S., ed. 2003. The pesticide manual: a world compendium, 13th edition. The British Crop Protection Council. 1250 pp., ISBN 1 901396 13 4.

- Cross resistance with existing fungicides;

Table 1. FRAC's classification of fungicides registered for use in Florida by FRAC numerical code, mode of action, chemical group, and active ingredient common name with high risk indication.

FRAC code*	Mode of action	Group name	Chemical group	Common name	Resistance risk indication
1	Inhibition of mitosis and cell division	MBC fungicides	Benzimidazoles Thiophanates	Carbendazim Thiabendazole Thiophanate-methyl	HIGH RISK
2	Inhibition of lipids and membrane synthesis	Dicarboximides		Iprodione Vinclozolin	MEDIUM to HIGH RISK
3	Inhibition of sterol biosynthesis in membranes	Demethylation inhibitors (DMI fungicides)	Imidazoles Piperazine Pyrimidines Triazoles	Imazalil Triforine Fenarimol Difenoconazole Fenbuconazole Myclobutanil Propiconazole Triadimefon	
4	Inhibition of nucleic acid synthesis	Phenyl Amides	Acylalanines	Metalaxyl Metalaxyl-M	HIGH RISK
5	Inhibition of sterol biosynthesis in membranes	Amines (SBI: Class II)	Piperidines	Piperalin	
6	Inhibition of lipids and membrane synthesis	Phosphoro-thiolates, dithiolanes	None registered for use in Florida	None registered for use in Florida	
7	Inhibition of respiration	Carboxamides		Carboxin Flutolanil Oxycarboxin	
8	Inhibition of nucleic acid synthesis	Hydroxy-(2-amino) pyrimidines	None registered for use in Florida	None registered for use in Florida	
9	Inhibition of amino acids and protein synthesis	Anilino-pyrimidines		Cyprodinil	
10	Inhibition of mitosis and cell division	N-phenyl carbamates	None registered for use in Florida	None registered for use in Florida	
11	Inhibition of respiration	Quinone outside inhibitors (QoI fungicides)	Methoxy-acrylates Methoxy-carbamates Oximino acetates Oxazolidine-diones	Azoxystrobin Pyraclostrobin Kresoxim methyl Trifloxystrobin Famoxadone	HIGH RISK
12	Inhibition of signal transduction	Phenyl Pyrroles (PP fungicides)		Fludioxonil	
13	Inhibition of signal transduction	Quinolines	None registered for use in Florida	None registered for use in Florida	
14	Inhibition of lipids and membrane synthesis	Aromatic hydrocarbons (AH fungicides)		Chloroneb Dicloran PCNB	
15	Inhibition of glucan and cell wall synthesis	Cinnamic acids	None registered for use in Florida	None registered for use in Florida	

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FRAC code*	Mode of action	Group name	Chemical group	Common name	Resistance risk indication
16.1	Inhibition of melanin synthesis in cell wall	Melanin biosynthesis inhibitors – reductase (MBI-R fungicides)	None registered for use in Florida	None registered for use in Florida	
16.2	Inhibition of melanin synthesis in cell wall	Melanin biosynthesis inhibitors – dehydratase	None registered for use in Florida	None registered for use in Florida	
17	Inhibition of sterol biosynthesis in membranes	Hydroxyanilides (SBI: Class III)		Fenhexamid	
18	Inhibition of sterol biosynthesis in membranes	(SBI: Class IV)	None registered for use in Florida	None registered for use in Florida	
19	Inhibition of glucan and cell wall synthesis	Polyoxins	Peptidyl pyrimidine nucleoside	Polyoxin	
20	Inhibition of mitosis and cell division	Phenylureas	None registered for use in Florida	None registered for use in Florida	
21	Inhibition of respiration	Quinone inside inhibitors (Qil fungicides)		Cyazofamid	MEDIUM to HIGH RISK
22	Inhibition of mitosis and cell division	Benzamides		Zoxamide	
23	Inhibition of amino acids and protein synthesis	Enopyranuronic acid antibiotic	None registered for use in Florida	None registered for use in Florida	
24	Inhibition of amino acids and protein synthesis	Hexopyranosyl antibiotic	None registered for use in Florida	None registered for use in Florida	
25	Inhibition of amino acids and protein synthesis	Glucopyranosyl antibiotic		Streptomycin	HIGH RISK
26	Inhibition of glucan and cell wall synthesis	Glucopyranosyl antibiotic	None registered for use in Florida	None registered for use in Florida	
27	Unknown	Cyanoacetamide-oximes		Cymoxanil	
28	Inhibition of lipids and membrane synthesis	Carbamates		Propamocarb	
29	Inhibition of respiration		2,6-dinitroanilines	Fluazinam	
30	Inhibition of respiration	Organo tin compounds	Tri phenyl tin compounds	Fentin hydroxide	
31	Inhibition of nucleic acid synthesis	Carboxylic acids	None registered for use in Florida	None registered for use in Florida	
32	Inhibition of nucleic acid synthesis	Heteroaromatics	Isothiazolones	Octhilinone	

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FRAC code*	Mode of action	Group name	Chemical group	Common name	Resistance risk indication
33	Unknown	Phosphonates	Ethyl phosphonates	Fosetyl-Al Phosphorous acid	
34	Unknown	Pthalamic acids	None registered for use in Florida	None registered for use in Florida	
35	Unknown	Benzotriazines	None registered for use in Florida	None registered for use in Florida	
36	Unknown	Benzene-sulfonamides	None registered for use in Florida	None registered for use in Florida	
37	Unknown	Pyridazinones	None registered for use in Florida	None registered for use in Florida	
38	ATP production (proposed)		Thiophene-carboxamides	None registered for use in Florida	
39	Complex I of respiration (proposed)		Pyrimidinamides	None registered for use in Florida	
40	Phospholipid biosynthesis and cell wall deposition (proposed)	CAA-fungicides (carboxylic acid amides)	None registered for use in Florida	None registered for use in Florida	
41	Protein synthesis attachment of aminoacyl-tRNA to ribosomal acceptor (A) site	Tetracycline antibiotic		Oxytetracycline	HIGH RISK
42	Unknown	Thiocarbamate	None registered for use in Florida	None registered for use in Florida	
P	Host plant defense induction	Salicylic acid pathway P1	Benzothiadazole (BTH)	Acibenzolar	
M	Multi-site contact activity	M1 M2 M3 M4 M5 M6 M7 M8 M9	Inorganics Inorganic Dithio-carbamates and relatives Phthalimides Chloronitriles Sulphamides Guanidines Triazines Quinones (anthraquinones)	Copper (different salts) Sulfur Ferbam Mancozeb Maneb Metiram Thiram Ziram Captan Folpet Chlorothalonil None registered for use in Florida Dodine None registered for use in Florida None registered for use in Florida	
NC	Not classified	NC	Diverse	Oils Potassium bicarbonate	

Table 2. Cross listing of active ingredient common names with trade products registered for use in Florida.

Common name	Trade products*®
Acibenzolar	Actigard
Azoxystrobin (HIGH RISK)	Abound, Amistar, Dynasty, Heritage, Protégé, Quadris, Quilt, Uniform
Captan	Agrox Premiere, Captan, Captec, Captivate, Fungitrol C, Kernel Guard, Maxima HB, Rescue One, SA-50, TCI, Vitavax PC
Carbendazim (HIGH RISK)	Mauget, Mergal, Polyphase, Rocima
Carboxin	Allerax, Kickstart, Prevail, Vitavax
Chloroneb	Catapult, Delta Coat, Teremec, Nu-Coat
Chlorothalonil	Applause, Banol C, Bravado, Bravo, Busan, Chloro Gold, Chloronil, Chlorosel, Chlorostar, Chlorothalonil, Concorde, Consyst, Daconil, Echo, Equus, Fungonil, Manicure, Maxcide, Nopocide, Nucide, Pathguard, Pro Tech, Quadris, Quali-Pro, Ridomil Gold, SA-50, Spectro, Thor, Twosome
Copper (carbonate)	Captain, Nautique, Wolman E
Copper (chelates of copper citrate)	Algimycin, Bioguard, Bordeaux, Pool Time
Copper (ethanolamine complex)	Various swimming pool treatments
Copper (ethylenediamine complex)	Various aquatic herbicides
Copper (hydroxide)	Champ, Champion, Cobra Rod, Cu-Bor, Funguran OH, Junction, Kocide, Kop-Hydroxide, Mankocide, Neptune, Nu-Cop, Ridomil Gold Copper, Spin Out,
Copper (I oxide)	Various anti-fouling paints
Copper (II oxide)	Various wood preservatives
Copper (metallic)	Various algaecides and anti-fouling paints
Copper (naphthenate)	Various wood preservatives
Copper (oxychloride)	Agra Cop, Coc, Kop Oxy 85, Microperse
Copper (salts of fatty and rosin acids)	Camelot, SA-50, Sunniland Coppercide, Tenn-Cop
Copper (sulfate pentahydrate)	Various swimming pool treatments
Copper (sulfate, anhydrous)	Copper-Z 4/4
Copper (triethanolamine complex)	Various algaecides and other water treatments
Cyazofamid (MEDIUM to HIGH RISK)	Ranman
Cymoxanil	Curzate, Tanos
Cyprodinil	Switch, Vangard
Dicloran	Botran
Difenoconazole	Dividend, Incentive
Dodine	Dodine, Elast, Syllit
Famoxadone (HIGH RISK)	Tanos
Fenarimol	Rubigan, Twosome
Fenbuconazole	Enable, Indar
Fenhexamid	Captevate, Decree, Elevate,
Fentin hydroxide	Agri Tin, Enable, Orbit, Super Tin
Ferbam	Ferbam
Fluazinam	Omega
Fludioxonil	Apron, Dynasty, Graduate, Maxim, Medallion, Scholar, Switch, Warden
Flutolanil	Artisan, Contrast, Moncoat, Moncut, Prostar, Sysstar

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Common name	Trade products*®
Folpet	Folpet, Fungitrol, several wood preservatives
Fosetyl-Al	Aliette, Prodigy, Signature
Imazalil	Clinafarm, Deccoil, Freshgard, Fungaflor, Magnate
Iodocarb	Many commercial preservative products available
Iprodione	Iprodione, Lesco 18 Plus, Rovral, Sextant
Kresoxim-methyl (HIGH RISK)	Cygnus, Sovran
Mancozeb	Acrobat MZ, Clean Crop Potato Seed, Cuprofix MZ, Dithane, Fore, Gavel, Junction, Mancozide, Manhandle, Manzate, Maxim, Moncoat, Nubark, Pentathlon, Penncozeb, Protect, Ridomil Gold MZ, Stature, Tops MZ Gaucho, Ziban
Maneb	Maneb, Manex, Pentathlon, Seed Treatment for Potatoes
Mefenoxam (HIGH RISK)	Agrox Premier, Allegiance, Allerax, Apron, Catapult, Delta Coat, Dividend, Dynasty, Flouronil, Incentive, Maxim, Mefenoxam, Meta-Mil, Prevail, Quell, Ridomil Gold, Subdue, System 3, Ultra Flourish, Uniform
Metiram	Polyram
Myclobutanil	Eagle, Immunox, Laredo, Manhandle, Nova, Systhane,
Octhilinone	Arch, Dobercide, Kathon, Mergal, Milbrex, Rocima, Skane, Tex-Stat, Thor
Oils	Biozide, Decident
Oxycarboxin	Plantivax, Provax
Oxytetracycline (HIGH RISK)	Flameout, OTC, Star Brite
Phosphorous acids	Magellan, Phostrol
Piperalin	Pipron
Polyoxin	Endorse
Potassium bicarbonate	Agricure, Armicarb, Kaligreen
Propamocarb	Banol, Previcur
Propiconazole	Alamo, Banner, Busan, Contend, Honor Guard, Infuse, Montero, Orbit, Premier, Propensity, Quilt, Spectator, Stratego, Tilt
Pyraclostrobin (HIGH RISK)	Cabrio, Headline, Insignia, Pristine
PCNB	Blocker, Defend, Parflo, Prevail, Revere, System 3, Terraclor, Turfcide, Vitavax
Streptomycin (HIGH RISK)	Agri Mycin, Bac-Master, Firewall, Seed Treatment for Potatoes, Streptrol
Sulfur	Many commercial products
Thiabendazole (HIGH RISK)	Add-2, Decco Salt, Di-All, Fresh Ban, Fresh Mark, Freshgard, Irgagard, Metasol, Post Harvest Lustr, Shield-Brite, Sta-Fresh, Stay-Clean, Super Mildex
Thiophanate-methyl (HIGH RISK)	Banrot, Cavalier, Fungo, Quali-Pro, Tee-Off, Topsin,
Thiram	Allerax, Bulb Saver, Defiant, Raxil, Spotrete, TCI Protector L, Thiram, Vitavax
Triadimefon	Armada, Bayleton, Fung Away, Fungisol, Fung-Onil, Strike
Trifloxystrobin (HIGH RISK)	Armada, Compass, Flint, Gem, Twist, Stratego
Triforine	Orthenex, Rosepride
Vinclozolin	Curalan, Touche
Ziram	Vancide, Ziram
Zoxamide	Gavel

Table 2. Cross listing of active ingredient common names with trade products registered for use in Florida.

Common name	Trade products*®
*Trade product contains at least this sole active ingredient, but may be pre-mixed with additional active ingredients. Consult product label ingredient statements.	