

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

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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 common names for active ingredients -- with corresponding examples of their trade names -- is also provided.

Fungicide-resistant plant pathogens are not new. Although the first confirmation of fungicide resistance 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 shortening amount of time taken for resistance to emerge, sometimes within two years of a new commercial fungicide introduction.

Fungicide resistance is not unique to plant pathogens. Insecticide-resistant insects, herbicide-resistant weeds and antibiotic-resistant bacteria are well documented. These resistant 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. By contrast, insects reproduce with multiple generations in a single year, and some bacteria and fungi reproduce several times in a single hour.

Where large populations exist, great genetic diversity exists within the population. Within these large 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.

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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, 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 phenomenon occurs when a plant pathogen is not controlled by fungicides that affect different plant-growth processes. For example, a plant pathogen that is resistant to fungicides that 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 by some manufacturers on their fungicide labels. 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, only those available in Florida. Those which have an intrinsic "high risk" of resistance evolution are identified. "High risk" is determined by the following indicators:

- Cross resistance with existing fungicides;
- 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 identify the mode-of-action 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.

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 resistance risk indication.

FRAC code*	Mode of action	Group name	Chemical group	Common name/resistance risk
4	Nucleic acids synthesis	PhenylAmides	Acylalanines	Metalaxyl Metalaxyl-M (Mefenoxam) HIGH RISK
32		Heteroaromatics	Isothiazolones	Othilinine RESISTANCE NOT KNOWN
1	Mitosis and cell division	MBC – Fungicides (Methyl Benzimidazole Carbamates)	Benzimidazoles	Carbendazim Thiabendazole HIGH RISK
			Thiophanates	Thiophanate-methyl HIGH RISK
22		Benzamides	Toluamides	Zoxamide LOW TO MEDIUM RISK
43			Pyridinylmethyl-benzamides	Fluopicolide RESISTANCE NOT KNOWN
7	Respiration	Carboxamides	Phenylbenzamides	Flutolanil MEDIUM RISK
			Oxathiincarboxamides	Carboxin Oxycarboxin MEDIUM RISK
			Pyridinecarboxamides	Boscalid MEDIUM RISK
11		QoI – fungicides (Quinone outside Inhibitors)	Methoxy acrylates	Azoxystrobin HIGH RISK
			Methoxy carbamates	Pyraclostrobin HIGH RISK
			Oximinoacetates	Kresoxim-methyl Trifloxystrobin HIGH RISK
			Oxazolidinediones	Famoxadone HIGH RISK
			Dihydrodioxazines	Fluoxastrobin HIGH RISK
			Imidazolinones	Fenamidone HIGH RISK
29	Uncouplers of oxidative phosphorylation	2,6-dinitrophenyl crotonates	Fluazinam LOW RISK	
30	Organo tin compounds	Tri phenyl tin compounds	Fentin hydroxide LOW TO MEDIUM RISK	

Table 1, continued. 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 resistancerisk indication.

9	Amino acids and protein synthesis	AP – fungicides (Anilino-Pyrimidines)	Anilino-pyrimidines	Cyprodinil Pyrimethanil MEDIUM RISK
25		Glucopyranosyl antibiotic	Glucopyranosyl antibiotic	Streptomycin HIGH RISK
41		Tetracycline antibiotic	Tetracycline antibiotic	Oxytetracycline HIGH RISK
13	Signal transduction	Quinolines	Quinolines	Quinoxifen MEDIUM RISK
12		PP -fungicides (PhenylPyrroles)	Phenylpyrroles	Fludioxonil LOW TO MEDIUM RISK
2		Dicarboximides	Dicarboximides	Iprodione Vinclozolin MEDIUM TO HIGH RISK
14	Lipids and membrane synthesis	AH -fungicides (Aromatic Hydrocarbons)	Aromatic hydrocarbons	Chloroneb Dicloran Quintozene (PCNB) LOW TO MEDIUM RISK
		Heteroaromatics	1,2,4-thiadiazoles	Etridiazole LOW TO MEDIUM RISK
28		Carbamates	Carbamates	Propamocarb LOW TO MEDIUM RISK
40		CAA -fungicides (Carboxylic Acid Amides)	Cinnamic acid amides	Dimethomorph LOW TO MEDIUM RISK
	Mandelic acid amides		Mandipropamid LOW TO MEDIUM RISK	

Table 1, continued. 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 resistance risk indication.

3	Sterol biosynthesis in membranes	DMI-fungicides (DeMethylation Inhibitors)	Piperazines	Triforine MEDIUM RISK
			Pyrimidines	Fenarimol MEDIUM RISK
			Imidazoles	Imazalil Triflumizole MEDIUM RISK
			Triazoles	Difenoconazole Fenbuconazole Ipconazole Metconazole Myclobutanil Propiconazole Prothioconazole Tebuconazole Tetraconazole Triadimefon Triadimenol MEDIUM RISK
5		Amines (Morpholines)	Piperidines	Piperalin LOW TO MEDIUM RISK
17		Hydroxyanilides	Hydroxyanilides	Fenhexamid LOW TO MEDIUM RISK
19	Glucan synthesis	Polyoxins	Peptidyl pyrimidine nucleoside	Polyoxin MEDIUM RISK
P	Host plant defense induction	Benzo-thiadiazole	Benzo-thiadiazole	Acibenzolar-S-methyl RESISTANCE NOT KNOWN
27	Unknown mode of action	Cyanoacetamide-oxime	Cyanoacetamide-oxime	Cymoxanil LOW TO MEDIUM RISK
33		Phosphonates	Ethyl phosphonates	Fosetyl-Al Phosphorous acid and salts LOW RISK
NC		Diverse	Diverse	Mineral oils Organic oils Potassium bicarbonate Material of biological origin RESISTANCE NOT KNOWN

Table 1, continued. 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 resistance risk indication.

M1	Multi-site contact activity	Inorganic	Inorganic	Copper (different salts) LOW RISK
M2				Sulfur LOW RISK
M3		Dithiocarbamates and relatives	Dithiocarbamates and relatives	Ferbam Mancozeb Maneb Metiram Thiram Ziram LOW RISK
M4		Phthalimides	Phthalimides	Captan Folpet LOW RISK
M5		Chloronitriles	Chloronitriles	Chlorothalonil LOW RISK
M7		Guanidines	Guanidines	Dodine Resistance reported in <i>Venturia inaequalis</i> suggesting that dodine may not be a multi-site inhibitor. Resistance management recommended

*Numbers and letters are used to distinguish the fungicide groups. The numbers were assigned primarily according to the time of product introduction to the market. The letter abbreviations are as follows: P = host plant defense inducers; M = multi-site contact activity; and NC = not classified.

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

Common name	Trade products*®
Acibenzolar-S-methyl	Actigard, Blockade
Azoxystrobin (HIGH RISK)	Abound, Amistar, Azo-Shield, Azotech, Dynasty, Headway, Heritage, Highway, Quadris, Quilt, Seed Shield, Sporgard, Uniform
Boscalid	Endura, Pristine
Captan	Captan, Captec, Captevate, Enhance, Fungitrol, SA-50, TCI, Trilex, Vitavax PC
Carbendazim (HIGH RISK)	Fungiblock, Mauget, Mergal, Polyphase, Rocima, placeCityTroy Mergal, Troysan
Carboxin	Allerax, Cotgard, Enhance, Kernel Guard, Kickstart, Latitude, Prevail, Vitavax
Chloroneb	Catapult, Terraneb, Nu-Coat

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

Chlorothalonil	Acticide PAX, Applause, Bravo, Busan, Chemnut, Chemtreat, Chloronil, Chlorostar, Chlorothalonil, Concorde, Countdown, Daconil, Densil, Disarm, Docket, Echo, Ensign, Equus, Flouronil, Fungitrol, Initiate, Instrata, Mainsail, Manicure, Maxide, Mold-Ram Nipcocide, Pegasus, Peregrine, Prominence, Quadris, Quali-Pro, Regal Consyst, Ridomil Gold, Rocima, SA-50, Sipcam, Spectro, Tee-1-Up, Thor, Tilt, TM + CTN
Copper (carbonate)	CMC, Micropro, Phibrowood, Sustain, UCU, Wolman E
Copper (ethanolamine complex)	Various swimming pool treatments
Copper (ethylenediamine complex)	Current, Harpoon, Komeen, Pondmaster
Copper (hydroxide)	Champ, Champion, Cu-Bor, Cupro, Funguran, GX-569, Junction, Kentan, Kocide, Kop-Hydroxide, Mankocide, Neptune, Nu-Cop, Ridomil Gold Copper, Spin Out,
Copper (metallic)	Various algaecides and anti-fouling paints
Copper (naphthenate)	Various wood preservatives
Copper (oxychloride)	placeCityAgra Cop, Badge, COC, Kocide COC
Copper (salts of fatty and rosin acids)	Camelot, Tenn-Cop
Copper (sulfate pentahydrate)	Various swimming pool treatments
Copper (triethanolamine complex)	Various algaecides and other water treatments
Copper (I oxide)	Various anti-fouling paints
Copper (II oxide)	Various wood preservatives
Cymoxanil	Curzate, Evolve, Tanos
Cyprodinil	Switch, Vangard
Dicloran	Botran
Difenoconazole	Cruiser, Dividend, Inspire, Revus, Seed Shield
Dimethomorph	Acrobat
Dodine	Elast, Syllit
Famoxadone (HIGH RISK)	Tanos
Fenamidone (HIGH RISK)	Reason
Fenarimol	Rubigan
Fenbuconazole	Enable, Indar
Fenhexamid	Captevate, Decree, Elevate,
Fentin hydroxide	Agri Tin, Enable, Orbit, Super Tin
Ferbam	Ferbam
Fluazinam	Omega
Fludioxonil	Apron, Cruiser, Dynasty, Fludi-Shield, Graduate, Hurricane, Instrata, Maxim, Medallion, Scholar, Seed Shield, Sporgard, Switch
Fluoxastrobin (HIGH RISK)	Evito
Flutolanil	Artisan, Contrast, Convoy, Moncoat, Moncut, Prostar, Sysstar
Folpet	Folpet, Fungitrol, several wood preservatives
Fosetyl-Al	Aliette, Autograph, Avalon, Flanker, Legion, Linebacker, Novasource, Prodigy Signature, Quali-Pro
Imazalil	Clinafarm, Deccoziil, Freshgard, Fungaflor, Magnate, Pacrite
Ipconazole	Vortex
Iprodione	26/36, 26GT, placeCityAndersons, Chipco, Dovetail, Iprodione, Lesco, Nevado, OHP, Primeraone, Quali-Pro, Raven, Rovral, Sextant, TM + IP
Kresoxim-methyl (HIGH RISK)	Cygnus, Sovran

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

Mancozeb	Acrobat MZ, Clevis, Cuprofix MZ, Dithane, Evolve, Fore, Gaucho, Gavel, Junction, Mancozide, Manhandle, Manzate, Maxim, Moncoat, Nubark, Penncozeb, Pentathlon, Potato Seed Treater, Protect, Ridomil Gold MZ, SA-50, Stature, Tops MZ, Wingman, Zyban
Maneb	Maneb, Manex, Pentathlon
Metalaxyl (HIGH RISK)	Acquire, Allegiance, Allerax, Catapult, Cotgard, Latitude, Metastar, Prevail, Sebring, System 3, Trilex
Metalaxyl-M (Mefenoxam) (HIGH RISK)	Apron, Axle, Cruiser, Dividend, Dynasty, Fenox Flouronil, Hurricane, Mefenoxam, Ridomil Gold, Seed Shield, Subdue, Twist, Ultra Flourish, Uniform
Metiram	Polyram
Myclobutanil	Clevis, Dynasty, Eagle, Green Light, Greenview, Hoist, Immunox, CityLaredo, Manhandle, Nova, Rally, Schultz, placeCitySonoma
Octhilinone	Acticide, Arch, Bio/Tec 95, Cleanwood, Dobercide, Kathon, Mergal, Milbrex, Moldex, Rocima, Skane, Tex-Stat, Thor, Troysan
Oxycarboxin	Provax
Oxytetracycline (HIGH RISK)	Bacastat, Fireline, Flameout, OTC
Phosphorous acid	Magellan, Phostrol
Piperalin	Pipron
Polyoxin	Endorse, Veranda
Propamocarb	Banol, Previcur, Proplant, Stellar
Propiconazole	Alamo, Antiblu, Artisan, Banner, Bumper, Busan, Concert, Dorado, Fathom, Frameguard, Headway, Highway, Honor Guard, Instrata, Kestrel, Kop-Coat, Monterey, Mycostat, Orbit, Pack PT, Premier, Primeraone, Procon, Propensity, Propimax, Prosan, Quilt, Savvi, Spectator, Stratego, Tilt, Tranquillizer, Troysan, Wolman
Pyraclostrobin (HIGH RISK)	Cabrio, Coronet, Diamir, Headline, Insignia, Pageant, Pristine, Stamina, Twinline
PCNB	Blocker, Parflo, Prevail, System 3, Terraclor, Turfcide, Vitavax
Pyrimethanil	Penbotec, Scala
Quinoxifen	Quintec
Streptomycin (HIGH RISK)	Agri Mycin, Bac-Master, Firewall, Streptrol
Sulfur	Many commercial products
Thiabendazole (HIGH RISK)	Add-2, Arbotect, Azotect, Decco Salt, Freshgard, Irgagard, Krud Kutter, Mertect, Metasol, Shield-Brite, Sporgard, Stay-Clean, Super Mildex, Tecto
Thiophanate-methyl (HIGH RISK)	26/36, 3336, Allban, Banrot, Cavalier, Consyst, Dovetail, Evolve, Fungo, Infuse, OHP, Peregrine, Primeraone, Prominence, Quali-Pro, SA-50, Spectro, Sysstar, Systec, T-Bird, T-Methyl, Tee-1-Up, Tee-Off, TM, Tops, Topsin, Transom, T-Storm, Trilex Star
Thiram	42-S, Allerax, Defiant, Raxil, Rootone, Spotrete, Protector L, Vitavax
Triadimefon	SA-50, Armada, Bayleton, Fung Away, Fung-Onil, Strike, Tartan, Turf
Triadimenol	Trilex
Trifloxystrobin (HIGH RISK)	Absolute, Adament, Armada, Compass, Distinguish, placeCityFlint, Gem, Stratego, Tartan, Trilex
Triforine	Orthenex, Rosepride
Vinclozolin	Curalan, Touche
Ziram	Vancide
Zoxamide	Gavel

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

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

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Read and follow directions on the manufacturer's label.