

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

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This guide addresses management of pesticide resistance and describes the Fungicide Resistance Action Committee's (FRAC) classification of fungicides and bactericides registered for agricultural and non-agricultural use in Florida by their modes of action. A cross-reference of common names for active ingredients, along 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 occurrences until 1970. Since then, fungicide resistance has not been infrequent, especially with the introduction of systemic fungicides. There has been concern that the time it takes for resistance to emerge has been shortening. Sometimes resistance occurs within two years of a new commercial fungicide introduction. The development of rapid resistance is related to the increased specificity of targets and selection pressure on the target population.

Resistance problems are 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: 1) they have exceptionally large populations and 2) a rapid rate of

reproduction. Weeds were the last category of pests to show resistance because there is a very large seed bank in the soil with many individuals that have limited pesticide exposure. In contrast, insects reproduce with multiple generations in a single year, and some bacteria reproduce several times in a single hour. In both cases, there is less of a population reservoir with these organisms.

Where large populations exist, great genetic diversity exists in the population. In these large populations, several individuals will be tolerant of chemical-control measures, perhaps only one in a million or one in a billion. Pests typically become resistant when the same pesticide is used repeatedly within a single year or for several consecutive years. Some individuals believed that selection pressure forced pests to mutate, but this view has been largely discounted through research. However, more accepted reasons for resistance are as follows:

- There was always a small resistant population present from natural variation.
- When a pesticide is applied, the susceptible population is controlled, but the smaller, resistant population becomes a larger proportion of the population that re-infests the site.

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Cross-Resistance versus Multiple-Resistance

Agricultural producers in Florida have the option of using more than 50 different fungicide active ingredients and many more trade products, including mixtures. Many of these active ingredients work in the same way; in other words, they have the same *mode of action*. Despite the numerous trade products available, these fungicides affect fewer than 20 growth mechanisms.

A plant pathogen is cross-resistant when it cannot be controlled by fungicides affecting the same growth process. An example of a plant pathogen that has cross-resistance is one resistant to fungicides in the triazoles or pyrimidines chemical groups. Both of these are demethylation inhibitors (DMI) that 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 growth processes. For example, if a plant pathogen is resistant to fungicides that inhibit both mitosis and protein synthesis, two different fungal growth processes, it would be labeled as having multiple-resistance.

Fungicide Selection

Farmers and crop advisors need to know which fungicides are best suited to combat resistant plant pathogens. Some manufacturers use the FRAC numerical classification of fungicides (listed in Table 1) to support the use of fungicides in a manner suitable for resistance management. 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 only include fungicides available in Florida. Those with an intrinsic “high risk” of resistance selection are identified. “High risk” is determined by the following:

Fungicide Indicators

- The product activity persists over time, or there is the practice of repetitive use or sustained treatments.
- There is only one target for the mode of action.
- Only one gene needs to be mutated for a fungus to be no longer susceptible.
- The product is easily metabolized by the target fungus.

Pathogen Indicators

- There is cross-resistance with existing fungicides.
- There is high genetic variability within the target plant pathogen population.
- The target plant pathogens are known to have large populations with rapid multiplication.
- The target plant pathogen multiplies rapidly with frequent generations.
- Some target organisms possess the ability to metabolize products.
- There are no harmful effects on resistant individuals.

FRAC encourages fungicide registrants to use this system 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.

Agricultural producers can have difficulty keeping track of which modes of action they use because of the great variety of trade names and package mixtures of fungicides.

Additional Information

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

FRAC code*	Mode of action	Target site of action	Active ingredient common name	Resistance risk
4	Nucleic acid synthesis	RNA polymerase I	Metalaxyl	HIGH
			Metalaxyl-M (Mefenoxam)	
32		DNA/RNA synthesis (proposed)	Octhilinone	RESISTANCE NOT KNOWN
1	Mitosis and cell division	β -tubulin assembly in mitosis	Carbendazim	HIGH
			Thiabendazole	
			Thiophanate-methyl	
22			Zoxamide	LOW TO MEDIUM
43		Delocalisation of spectrin-like proteins	Fluopicolide	RESISTANCE NOT KNOWN
7	Respiration	Complex II: succinate-dehydrogenase	Flutolanil	MEDIUM TO HIGH
			Carboxin	
			Fluopyram	
			Boscalid	
11		Complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)	Azoxystrobin	HIGH
			Pyraoxystrobin	
			Pyraclostrobin	
	Kresoxim-methyl			
	Trifloxystrobin			
	Famoxodone			
	Fluoxastrobin			
	Fenamidone			
21		Complex III: cytochrome bc1 (ubiquinone reductase) at Qi site	Cyazofamid	RESISTANCE RISK UNKNOWN BUT ASSUMED TO BE MEDIUM TO HIGH
29		Uncouplers of oxidative phosphorylation	Fluazinam	LOW
30		Inhibitors of oxidative phosphorylation, ATP synthase	Fentin hydroxide	LOW TO MEDIUM
9	Amino acids and protein synthesis	Methionine biosynthesis (proposed) (<i>cgs</i> gene)	Cyprodinil	MEDIUM
			Pyrimethanil	
25		Protein synthesis (bactericides)	Streptomycin	HIGH
41	Oxytetracycline			
13	Signal transduction	Mechanism unknown	Quinoxifen	MEDIUM
12		MAP/Histidine-kinase in osmotic signal transduction (<i>os-2</i> , <i>HOG1</i>)	Fludioxonil	LOW TO MEDIUM
2		MAP/Histidine-kinase in osmotic signal transduction (<i>os-1</i> , <i>Daf1</i>)	Iprodione	MEDIUM TO HIGH Cross-resistance common
	Vinclozolin			

FRAC code*	Mode of action	Target site of action	Active ingredient common name	Resistance risk
14	Lipid synthesis and membrane integrity	Lipid peroxidation (proposed)	Chloroneb	LOW TO MEDIUM
			Dicloran	
			Etridiazole	
28		Cell membrane permeability, fatty acids (proposed)	Propamocarb	
44		Microbial disrupters of pathogen cell membranes	<i>Bacillus subtilis</i>	ASSUMED TO BE LOW
3	Sterol biosynthesis in membranes	C14-demethylase in sterol biosynthesis (<i>erg11/cyp51</i>)	Triforine	MEDIUM
			Fernarimol	
			Imazalil	
			Triflumizole	
			Cyproconazole	
			Difenoconazole	
			Fenbuconazole	
			Flutriafol	
			Ipconazole	
			Metconazole	
			Myclobutanil	
			Propiconazole	
			Prothioconazole	
			Tetraconazole	
	Triadimefon			
	Triadimenol			
	Triticonazole			
5		Δ^{14} -reductase and Δ^8 Δ^7 -isomerase in sterol biosynthesis (<i>erg24, erg2</i>)	Piperalin	LOW TO MEDIUM
17		3-keto reductase, C4-demethylation (<i>erg27</i>)	Fenhexamid	
19	Cell wall biosynthesis	Chitin synthase	Polyoxin	MEDIUM
40		Cellulose synthase	Dimethomorph	LOW TO MEDIUM Cross-resistance
			Mandipropamid	
P	Host plant defense induction	P1: Salicylic acid pathway	Acibenzolar-S-methyl	NOT KNOWN
		P4 (proposed)	Laminarin	
27	Unknown mode of action	Unknown	Cymoxanil	LOW TO MEDIUM
33			Fosetyl-AI	LOW
			Phosphorous acid and salts	
U12		Cell membrane disruption (proposed)	Dodine	LOW TO MEDIUM
NC	Not classified	Diverse	Mineral oils, organic oils, potassium bicarbonate, material of biological origin	NOT KNOWN

FRAC code*	Mode of action	Target site of action	Active ingredient common name	Resistance risk
M1	Multi-site contact activity	Multi-site contact activity	Copper (different salts)	LOW
M2			Sulfur	
M3			Ferbam	
			Mancozeb	
			Maneb	
			Metiram	
			Thiram	
			Ziram	
M4			Captan	
M5			Folpet	
	Chlorothalonil			

*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; U = unknown mode of action; 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, Cruiser, Dynasty, Graduate A+, Headway, Heritage, Highway, Maxide, Maxim Quattro, Optishield, Quadris, Quadris Top, Quilt, Renown, Seed Shield, Sporgard, Trio Extra, Uniform
<i>Bacillus subtilis</i>	Companion, Histick, Integral, Kodiak, Premiere, Pro-Mix, Subtilex, System 3
Boscalid	Endura, Pristine
Captan	Captan, Captec, Captevate, Enhance, Fungitrol, Hi-Moly, Rescue, SA-50, Trilex, Vitavax PC
Carbendazim (HIGH RISK)	Bioban, Fungiblock, Mauget, Mergal, Polyphase, Rocima, Troysan
Carboxin	Allerax, Cotgard, Enhance, Kernel Guard, Latitude, Prevail, Vitavax
Chloroneb	IX, Teremec, Terramec
Chlorothalonil	Acticide PAX, Aftershock, Antiblu, Applause, Bravo, Busan, Catamaran, Chemtreat, Chloro Gold, Chloronil, Chlorosel, Chlorostar, Chlorothalonil, Chlortram, Cleanwood, CLT, Concert, Concorde, Consyst, Countdown, Daconil, Densil, Disarm, Docket, Echo, Ensign, Equus, Exotherm, Flouronil, Fungitrol, Fungonil, Initiate, Instrata, Legend, Mainsail, Manicure, Maxide, Mold-Ram Nopocicide, Pegasus, Peregrine, Prominence, Quadris, Quali-Pro, Renown, Reserve, Ridomil, Rocima, SA-50, Spectro, Tee-1-Up, Thalonil, Thor, Tilt, TM, Vitalonil
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 algacides and anti-fouling paints
Copper (naphthenate)	Various wood preservatives
Copper (oxychloride)	Agra Cop, Badge, COC
Copper (salts of fatty and rosin acids)	Camelot, Tenn-Cop
Copper (sulfate pentahydrate)	Various swimming pool treatments, Magna-Bon CS 2005, Phyton 27 AG
Copper (triethanolamine complex)	Various algacides and other water treatments

Common name	Trade products**
Copper (I oxide)	Various anti-fouling paints
Copper (II oxide)	Various wood preservatives
Cyazofamid	Ranman, Segway
Cymoxanil	Curzate, Evolve, Tanos
Cyproconazole	Alto, Quadris Xtra
Cyprodinil	Inspire Super, Palladium, Switch, Vanguard
Dicloran	Botran
Difenoconazole	Amdro, Cruiser, Dividend, Inspire, Quadris Top, Revus, Seed Shield
Dimethomorph	Acrobat, Forum, Stature
Dodine	Elast
Etridiazole	Banrot, Koban, Terraclor, Terramaster, Terrazole, Truban
Famoxadone (HIGH RISK)	Tanos
Fenamidone (HIGH RISK)	Fenstop, Reason
Fenarimol	Rubigan
Fenbuconazole	Enable, Indar
Fenhexamid	Captevate, Decree, Elevate
Fentin hydroxide	Agri Tin, Enable, Orbit, Super Tin
Ferbam	Ferbam
Fluazinam	Omega
Fludioxonil	Apron, Cannonball, Cruiser, Dynasty, Fludi-Shield, Graduate, Graduate A+, Hurricane, Instrata, Maxim, Medallion, Mozart, Optishield, Palladium, Scholar, Seed Shield, Sporgard, Switch, Trio Extra, Warden
Fluopicolide	Adorn, Presidio, Stellar
Fluopyram	Luna Experience, Luna Sensation, Luna Tranquility
Fluoxastrobin (HIGH RISK)	Aftershock, Disarm, Evito
Flutolanil	Artisan, Contrast, Convoy, Moncoat, Moncut, Prostar, Sysstar
Flutriafol	Topguard
Folpet	Folpet, Fungitrol, several wood preservatives
Fosetyl-Al	Aliette, Armortech, Autograph, Avalon, Flanker, Fosetyl-Al, Gimme, Legion, Linebacker, Novasource, Prodigy Signature, Viceroy
Imazalil	Clinafarm, Deccoziil, Freshgard, Fungaflor, Magnate, Pacrite
Ipconazole	Acceleron, Inovate, Rancona, Vortex
Iprodione	26/36, 26GT, Andersons, Armortech, Chipco, Dovetail, Enclosure, Iprodione, Lesco, Nevado, OHP, Primeraone, Quali-Pro, Raven, Rovral, Tazz, TM + IP
Kresoxim-methyl (HIGH RISK)	Cygnus, Sovran
Laminarin	Vacciplant
Mancozeb	Acrobat MZ, Clevis, Cuprofix MZ, Dithane, Evolve, Fore, Gaucho, Gavel, Junction, Koverall, Manco-Phite, Mancozeb, Mancozide, Manhandle, Manzate, Maxim, Moncoat, Penncozeb, Pentathlon, Potato Seed Treater, Protect, Ridomil Gold MZ, SA-50, Stature, Tops MZ, Wingman, Zyban
Mandipropamid	Revus
Maneb	Maneb, Manex
Metalaxyl (HIGH RISK)	Acceleron, Acquire, Allegiance, Allerax, Charter, Cotgard, Dyna-Shield, Inovate, Latitude, Metastar, Prevail, Protector, Rancona, Sebring, Spera, Stamina, System 3, Trilex
Metalaxyl-M (Mefenoxam) (HIGH RISK)	Apron, Axle, Cruiser, Dividend, Dynasty, Fenox Flouronil, Hurricane, Maxim, Mefenoxam, Ridomil Gold, Seed Shield, Subdue, Trio Extra, Twist, Ultra Flourish, Uniform, Warden
Metconazole	Caramba, Headline, Metlock, Quash, Tourney, Twinline
Metiram	Cabrio, Polyram

Common name	Trade products**
Mineral oils	435, 455, 692, 796, All Seasons, Biocover, Bonide, BVA, Civitas, Damoil, GB-1111, Mite-E-Oil, Omni, Parafine, Pervade, Pest Fighter, Prescription, Purespray, Ready-To-Use, RTSA, SA-50, Sol-Oil, Soluble Oil, Spray Fluid, Stylet Oil, Triangle, Volck, Year-Round
Myclobutanil	Acceleron, Armortech, Disarm, Dynasty, Eagle, F-Stop, Green Light, Greenview, Hoist, Immunox, Laredo, Manhandle, Myclobutanil, Myclotect, Nova, Rally, Siskin, Sonoma, Spera Coat
Octhilinone	Acticide, Arch, Bio/Tec 95, Bioban, Cleanwood, Intercept, Kathon, Moldex, Rocima, Skane, Tex-Stat, Thor, Troysan
Oxytetracycline (HIGH RISK)	Bacastat, Fireline, Mycoject, OTC
Phosphorous acid	Magellan, Phostrol
Piperalin	Pipron
Polyoxin	Affirm, Endorse, Ph-D, Veranda
Potassium bicarbonate	Armicarb, Kaligreen, Milstop
Propamocarb	Banol, Previcur, Promess, Proplant, Stellar
Propiconazole	Alamo, Amtide, Antiblu, Armortech, Artisan, Avaris, Banner, Bumper, Busan, CB-300, Concert, Dorado, Dual Action, Fathom, Fitness, Frameguard, Headway, Highway, Honor Guard, Instrata, Kestrel, Kop-Coat, Monterey, Mycostat, Orbit, Pack PT, Premier, Primeraone, Procon, Prophecy, Propensity, Propiconazole, Propimax, Propi-Star, Prosan, Quilt, Savvi, Shepherd, Solera, Spectator, Star-Shield, Stratego, Strider, Tilt, Troysan, Wocosen, Wolman
Prothioconazole	Proline, Prosaro, Provost, Stratego
Pyraclostrobin (HIGH RISK)	Acceleron, Cabrio, Coronet, Diamir, Headline, Honor, Insignia, Pageant, Pristine, Stamina, Twinline
Pyrimethanil	Distinguish, Freshgard, Luna Tranquility, Pacrite, Penbotec, Philabuster, Scala
Quinoxifen	Quintec
Streptomycin (HIGH RISK)	Ag Streptomycin, Agri Mycin, Firewall
Sulfur	Many commercial products
Tebuconazole	Absolute, Luna Experience
Tetraconazole	Domark, Mettle
Thiabendazole (HIGH RISK)	Add-2, Alumni, Azotech, Decco Salt, Freshgard, HDH, Krud Kutter, Maxim Quattro, Mertect, Metasol, Optishield, Shield-Brite, Sporgard, Stay-Clean, Tecto
Thiophanate-methyl (HIGH RISK)	26/36, 3336, Allban, Armortech, Banrot, Cavalier, Dovetail, Evolve, Fungo, Infuse, OHP, Peregrine, Primeraone, Prominence, Quali-Pro, Regal Consyst, SA-50, Spectro, Sysstar, Systec, T-Bird, T-Methyl, Tee-1-Up, Tee-Off, Thiophanate-methyl, TM, Tops, Topsin, Transom, T-Storm, Trilex Star
Thiram	42-S, Allerax, Defiant, Flowsan, Raxil, Rootone, Spotrete, Protector L, Thiram, Vitavax
Triadimefon	SA-50, Armada, Bayleton, Fung Away, Fungicide VII, Strike, Tartan, Turf
Triadimenol	Trilex
Trifloxystrobin (HIGH RISK)	Absolute, Acceleron, Adamant, Armada, Compass, Distinguish, Flint, Gem, Interface, Luna Sensation, Stratego, Tartan, Trilex
Triflumizole	Procure, Terraguard
Triforine	Orthenex, Rosepride
Triticonazole	Charter, Pillar, Reserve, Stamina, Trinity, Triton
Vinclozolin	Curalan, Touche
Ziram	Vancide, Ziram
Zoxamide	Gavel, Zoxium

*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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