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Fungicide Rotation for Nursery, Greenhouse, and Landscape Professionals

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Fungicides are important tools for managing ornamental plant diseases. There are many different fungicides and numerous methods of classifying them. This publication examines how fungicides are classified and recommends management practices to prevent fungi from developing resistance to these products.

Fungicide Class

One way to classify fungicides is by their chemical structures or modes of action — the specific ways the fungicides affect a fungus. Fungicides that share a common mode of action belong to the same **fungicide class** (sometimes referred to as a **fungicide family**). Unfortunately, if a fungus is resistant to a specific fungicide, it is usually resistant to all the fungicides within that fungicide class.

Target Site

Fungicides are also characterized by their specificity.

Site-specific fungicides react with one very specific, very important biochemical process, called the **target site**. For example, a fungicide target site could be the specific proteins involved in cell wall biosynthesis, RNA biosynthesis, or cell division. Sitespecific fungicides target these specific processes, which prevents the fungus from growing and ultimately causes its death.

Multi-site fungicides have multiple modes of action, so they affect multiple target sites, and simultaneously interfere with numerous metabolic processes of the fungus.

Fungicide resistance occurs when a fungus develops a genetic mutation at the target site that reduces its sensitivity to a specific fungicide. Because they affect multiple target sites, multi-site fungicides have a very low risk of causing fungicide resistance because it is highly unlikely for a fungus to simultaneously develop all of the mutations necessary for resistance.

Site-specific fungicides, however, have a much higher risk of causing resistance because a single genetic mutation at the target site can change a fungus' biochemical process so that it can still perform the needed biological function (cell division, membrane

biosynthesis, respiration). The result is a fungus strain that is less susceptible or no longer susceptible to the site-specific fungicide.

If a single fungicide continues to be used, the fungicide-sensitive portion of the population is suppressed over time, and only the fungicide-resistant portion of the population remains, which goes on to reproduce and make up the majority of the population. Eventually, the fungicide is ineffective because this majority of the fungal populationis no longer susceptible to it.

Minimizing Resistance

To minimize the possibility of fungicide resistance from occurring, implement a comprehensive management strategy before resistance develops. Some key tactics to include in your management strategy include:

1. **Follow good plant practices.**
   Using disease-resistant cultivars, following proper planting and fertilization techniques, and sanitizing equipment reduce the reliance on fungicides, thereby reducing the risk of their over-use and the development of resistant populations.
2. **Use the recommended doses as stated on fungicide lables.**
   Many fungicides have been extensively tested to identify the optimal rate. Cutting the rate results in a sublethal dose that is not only ineffective for disease management, but increases the risk of resistance.
3. **Minimize the number of fungicide treatments per season, and apply only when necessary.**
   Excessive use of site-specific fungicides increases the likelihood of resistance. By reducing the number of site-specific fungicide applications, you reduce the likelihood of resistance development.
4. **Do not rely solely on one fungicide with a site-specific mode of acton.**
   Use a diversity of fungicides with different modes of action that provide broad-spectrum disease control. There is no single, best fungicide. There are, however, multiple fungicides with different efficacies for different diseases. Many single-site fungicides are highly effective by themselves, but you should tank-mix them with another fungicide from a different family, or rotate or alternate multiple fungicides to reduce the risk of resistance. The important thing to remember is that you should avoid consecutive applications of site-specific fungicides.

Tank-mixing and Rotating

There are two tactics that can reduce the risk of fungicide-resistant pathogen populations: tank-mixing and rotating fungicides.

As the name suggests, **tank-mixing** consists of mixing a fungicide with a high resistance risk with another fungicide with a low or negligible resistance risk (Table 1).

Rotating fungicides involves alternating products that have different modes of action so that you avoid back-to-back treatments with any one site-specific fungicide.

Tank-mixing and rotating are important for two reasons. First, both practices limit the amount of time fungi are exposed to any one product. Second, other fungicides could potentially suppress any resistant populations before they have a chance to reproduce.

Selecting the proper tank mix or rotation partners in a fungicide resistance management program is critical. To develop an effective tank mix or rotation:

- Use fungicides with different Group Codes (Table 1), which denote different fungicide families. Remember, fungicides with different trade names can belong to the same chemical family!
- Always partner site-specific products with a multi-site inhibitor fungicide (Group Code M).
- Carefully read fungicide labels to determine if any fungicides cannot be mixed or rotated together.

Fungicide rotations can be simple or complex, depending on the problem and the pathogen that is causing it. For example, you may control a Septoria, Myrothecium, or Alternaria leaf spot by rotating a fludioxonil-based fungicide (Group Code 12) with a chlorothalonil-based fungicide (Group code M), thereby minimizing the risk of resistance in the Group Code 12 fungicide.

Other diseases may require more elaborate rotations. For example, downy mildew on snapdragon or lamium may require:

- A dimethomorph-based fungicide (Group Code 40).
- And then, mancozeb or copper (both Group M).
- And then, a phosphorous acid-based fungicide (Group Code M(33)).
- And then, a phenylamide (FRAC Code 4) or oxathiapiprolin(FRAC Code U15).

Furthermore, this rotation could only be repeated twice with the Group 40 fungicide — it is limited to two applications unless it is tank-mixed.

The bottom line is that tank-mixing or rotating fungicides reduces the possibility of resistance development. This is important as the labels on most newer, site-specific fungicides have strict use recommendations to minimize the risk of fungicide resistance, and protect the longterm efficacy of the product. By carefully following these recommendations, and using fungicides with different group codes, diseases and fungicide resistance can be carefully and effectively managed.

Table 1. Fungicides Labeled for Use on Ornamentals. This table provides the common and trade names of selected fungicides currently registered in the United States for use on ornamentals. It also provides the group code, major fungicide families and chemistries within these groups, and the risk of resistance developing due to using these fungicides. Products set in italics indicate that they are prohibited from greenhouse use. Products set in bold indicate that they are for greenhouse use only.

Group Code[1]	Fungicide Family[2] or Class	Common Name	Example Trade Name	Risk of Resistance[3]
1	benzimidazole or MBC	thiophanate-methyl	3336®, Cleary's 3336®	high
2	dicarboximide	iprodione	Chipco 26GT®, Iprodione Pro 2SE®	medium to high
3	demethylation inhibitor (DMI)	bayleton	Bayleton®, Strike®	medium
		metconazole	*Tourney®*	
		myclobutanil	Eagle®, Systhane®	
		propiconazole	*Banner Maxx®, Propiconazole® Mix partner of Concert II*	
		tebuconazole	*Torque®*	
		triflumizole	Procure®, Terraguard®	
		triforine	Funginex®, Saprol®	
		triticonazole	Trinity®	
4	phenylamide (PA)	mefenoxam	Subdue Maxx®	high for downy mildew and Pythium; low for Phytophthora
5	amines, morpholines	piperalin	Pipron®	low to medium
7	succinate dehydrogenase inhibitors (SDHI) — carboximides	benzovindiflupyr	Mix partner of Mural®	medium
		boscalid	Mix partner of Pageant®	
		fluopyram	Mix partner of Broadform®	
		flutalonil	Prostar®	
		fluxopyroxad	Mix partner of Orkestra®	
9	anilopyrimadine (AP)	cyprodinil	Mix partner of Palladium®	
11	quinone outside inhibitor (QoI). — strobilurins	azoxystrobin	Heritage®	high
		fenamidone	**Fenstop®**	
		fluoxastrobin	Fame SC®, Disarm®	
		pyraclostrobin	Mix partner of Orkestra®, Pageant®	
		trifloxystrobin	Compass®	
12	phenylpyrrole (PP)	fludioxonil	Medallion®	low to medium
14	aromatic hydrocarbons	dicloran	Botran 70®	low
		etridiazole	Terrazole®, Truban®	
17	hydroxyanilide	fenhexamid	Decree®	low to medium
18	antibiotic streptomyces	streptomycin	Agri-Mycin®, Agri-Step®	low to medium
19	polyoxin	polyoxin D	Endorse®	medium
21	cyano-imidazole	cyazofamid	Segway®	unknown
21(P)[4]	host plant defense inducers, systemic acquired resistance (SAR)	acibenzolar-S- methyl	Actigard®	low
		harpin	Messenger®	unknown
28	carbamate	propamocarb	Banol®	low to medium
40	cinnamic acid	dimethomorph, mandipropamid	Stature SC® Micora	low to medium
43	benzamides	fluopicolide	Adorn®	unknown
45	quinone inhibitor	ametoctradin	Orvego®	unknown
49	piperidinyl	oxathiapiprolin	Segovis®	unknown
M	multi-site activity chloroalkythios	captan	Captan®	low
	multi-site activity chloronitrile	chlorothalonil, chlorothalonil + propiconazole	Bravo®, Daconil Ultrex, Daconil Weatherstik® *Mix partner in Concert II®*	low
	multi-site activity dithiocarbamate	mancozeb, maneb, dimethyldithio-carbamate	Mancozeb®, Dithane®, Protect DF, Thiram®	low
	multi-site activity inorganics	copper	Champ®, Kocide 3000®, others	low
		sulfur	Microthiol Disperss®, sulfur	unknown
M (33)	multi-site activity phosphonate	fosetyl-aluminum	Aliette®	low to medium
		phosphorous acid	Alude®, BioPhos®	low to medium
U (15)	piperidinyl	oxathiapiprolin	Segovis®	unknown

1 The Fungicide Resistance Action Committee (FRAC) code is listed in parentheses under the EPA Group code when the codes differ. Neither system includes biofungicides.

2 For the sake of consistency, group codes, fungicide classes, fungicide names, and abbreviations are those used by FRAC and by the EPA Office of Pesticide Programs. This program is part of the pesticide classification system developed to assist growers in resistance management. Only fungicide registered in the USA are included.

3 Resistance risk is considered high when resistance has already been reported, or a specific, single gene mode of resitance is known within a few years under commercial use; Medium risk is associated with less frequent resistance developement, or when more than one gene is involved, and the risk is considered low when the fungicide has multi-site activity. Entries in this column were assigned by FRAC (www.frac.info). Labels for fungicides registered in the USA are accessible at www.greenbook.net and www.cdms.net/manuf/manuf.asp.

4 Although similarly described, the modes of action are different.

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