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Disease Management Strategies for Horticultural Crops

Fungicide Resistance Management for Pome Fruit

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Fungicides are important tools for managing diseases in pome fruit (apple and pear). There are many different fungicides and numerous methods of classifying them. This publication examines how fungicides are classified and recommends management practices particular to pome fruit that can prevent fungi from developing resistance to these products.

Fungicide Class

One way to classify fungicides is by their chemical structures or their **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. Site-specific 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 population is 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 health practices**.
   Most popular commercial apple and pear varieties are not disease resistant, so proper planting, pruning, fertilization, and sanitation can reduce reliance on fungicides, which in turn can lower the risk of their over-use and resistance. Fungicides cannot make up for bad management practices.
2. **Use the recommended doses as stated on fungicide labels.**
   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 action.**
   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 disease 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 may be simple or complex, depending on the disease and available fungicide groups. For example, the best bitter rot control will be provided by a number of multi-site fungicides and quinone-outside inhibitors (Group Code 11). Rotating a Group Code 11 fungicide with a Group Code M fungicide decreases the risk of the disease developing resistance to the Group Code 11 fungicides. Including a pre-mix fungicide like Pristine® provides two group codes, Group 11 + Group 7, further reducing the likelihood of the disease developing resistance.

Other diseases may require a more complex rotation cycle. For example, powdery mildew on apples may require:

- A demethylase inhibitor (Group Code 3).
- Then a multi-site fungicide such as sulfur (Group Code M)
- Then a benzimidazole (Group Code 1).
- Then another multi-site fungicide such as sulfur (Group Code M).

This example shows a rotation of products with several modes of action, which is designed to manage fungicide resistance. Always follow label directions, including how many times the fungicide may be sprayed in one season, but as a general rule, no single product should be applied more than four times in a season.

Table 1. Fungicides Labeled for Use on Pome Fruit. *This table provides the common and trade names of selected fungicides currently registered in the United States for use on pome fruit. 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.*

Group Code[1]	Fungicide Family or Class[2]	Common Name	Example Trade Names	Mobility	Risk of Resistance[3]
1	benzimidazoles or MBC	thiophanate-methyl	Topsin M®, Cleary's 3336®	xylem-mobile	high
3	demethylation inhibitor (DMI)	fenarimol	Rubigan EC®	xylem-mobile	medium
		fenbucanazole	Indar®		
		flutriafol	flutriafol		
		myclobutanil	Nova 40WP®/Rally 40 WP®		
		triadimefon	Bayleton 50WP®		
		trifluminazole	Procure®		
3 + 9	demethylation inhibitor (DMI) and anilinopyrimidine	difenconazole and cyprodinil	Inspire Super®	xylem-mobile/ locally systemic/ translaminar	medium
4	phenylamides (PA)	mefenoxam	Ridomil Gold EC®	xylem-mobile	high
4+M	phenylamides and dithiocarbamates	mefenoxam and mancozeb	Ridomil Gold MZ®	contact/ xylem-mobile	low
7	succinate- dehydrogenase inhibitors (SDHI)	benzovindiflupyr	Aprovia®	locally systemic	medium to high
		fluopyram	SDHI component in Luna Sensation®		
		fluxapyroxad	Secadis®		
		penthiopyrad	Fontelis®		
7 + 9	succinate- dehydrogenase inhibitors (SDHI) and anilinopyrimidine	fluopyram and pyrimethanil	Luna Tranquility®	locally systemic	medium to high
9	anilinopyrimidine	cyprodinil	Vanguard 75WG®	locally systemic/ translaminar	medium
		pyrimethanil	Scala 5SC®		
11	quinone outside inhibitors or strobilurins	kresoxim-methyl	Sovran®	locally systemic/ translaminar	high
		pyraclostrobin	Cabrio®, QoI component in Merivon® and Pristine®		
		trifloxystrobin	Flint®		
11 + 7	strobilurins and carboxamides	pyraclostrobin and boscalid	Pristine®	locally systemic	low to medium
		pyraclostrobin and fluxopyroxad	Merivon®		
		trifloxystrobin and fluopyram	Luna Sensation®		
18	antibiotic streptomycin	streptomycin	Streptomycin 17WP®, Agri-Mycin 17®	xylem-mobile	high
24	antibiotic kasugamycin	kasugamycin	Kasumin 2L®	contact	medium
29	2,6-dinitro-anilines	fluazinam	Omega 500F®	contact	low
41	antibiotic tetracycline	oxytetracycline	FlameOut 17WP®, Mycoshield 17WP®	locally systemic	high
	oxytetracycline hydrochloride	oxytetracycline (OTC)	FireLine 17WP®	systemic	high
M	guanidines	dodine	Syllit®	contact	low
	multi-site activity chloroalkythios	captan	Captan®		
	multi-site dithiocarbamates and relatives	ammoniate of zinc with dithiocarbamic acid	Polyram®		
		mancozeb, maneb, dimethyldithiocarbamate	Dithane M-45®, Mancozeb®, Penncozeb®		
		ziram	Ziram®		
	multi-site activity inorganic	copper	Bordeaux mixture, liquid copper		
		sulfur	Microthiol Disperss®, sulfur		
M (33)	multi-site phosphonates	fosetyl-aluminium	Aliette®	amphimobile	low
		phophorous acid	Agri-Fos®, Prophyt®, Phostrol®		

[1] *Codes of different fungicide classes given by the Fungicide Resistance Action Committee (FRAC).*

[2] *For consistency, FRAC and the U.S. Environmental Protection Agency Office of Pesticide Programs use the same group codes, fungicide classes, fungicide names, and abbreviations.*

[3] *Risk resistance is based on the mode of action. High risk products have a single site of action or those for which disease-resistant populations have been discovered. Medium risk products are associated with products where resistance is seen with the mutation of more than one target site or resistance formation is less frequent than that of high risk. The risks 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.*

The bottom line is that tank-mixing or rotating fungicides reduces the possibility of diseases from developing resistance to them. The resistance risk is especially high with site-specific products. But, by properly rotating products, carefully following manufacturer recommendations, and using fungicides with different group codes, diseases and fungicide resistance can be carefully and effectively managed.

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