Resistance Management for Postharvest Fungicides

Scholar®

Graduate

syngenta

Fungicides are very important tools for fruit decay control and fruit quality management. To preserve the utility of postharvest fungicides they should be used with resistance prevention in mind. With proper resistance management the viability of fungicides can be maintained for years to come.

Failure of a fungicide to provide its normal level of disease control can be due to many factors, including poor application timing, inadequate coverage, adverse environmental conditions or applicator errors. It may also be a sign of fungicide resistance. Development of resistance depends largely on how and when fungicides are used as these factors are the selection pressures that drive resistance development.

Scholar® and Graduate® are part of Syngenta's new line of postharvest fungicides. Other new postharvest fungicides from Syngenta and other companies will be introduced in the coming years. We strongly support resistance management to ensure that all new postharvest fungicides remain effective well into the future.

Although most postharvest diseases appear in the packinghouse, infections often begin in the field. For example, the fungus *Penicillium digitatum* (the pathogen that causes green mold) survives as spores from season to season in the orchard, and infections occur when airborne spores land on fruit, germinate, and the fungus penetrates the rind through wounds, punctures, or injured oil glands, etc.

Figure 1. Infections often begin in the field but symptoms of decay are not expressed until after harvest.

A **B** **C**

Infected fruit on the tree (1A) and up to harvest (1B) often do not exhibit symptoms or signs of infection. However, green mold can be isolated on nutrient agar from these seemingly healthy fruit. The environmental conditions in storage are ideal for the growth and sporulation of the fungus (1C). Therefore, both postharvest decay management and fungicide resistance management must begin in the field. By following the PACK RULES, you will have a strong resistance management program for postharvest fungicides.

Resistance Management in the Field

Prevent disease establishment by using effective field fungicide programs.

Avoid use of fungicides with related chemistries to any fungicide that potentially might be used in a packinghouse. (See Table 1.)

Cultural practices are critical. Avoid fruit bruising and injury during harvest and transport.

Keep it clean. Sanitize to reduce inoculum entry into the packinghouse:
– Use only clean bins and wash between loads;
– Never return culls from the packinghouse to the field.

Resistance Management in the Packinghouse

Rotate between different fungicide classes or use mixtures from different classes.

Use labeled rates.

Limit the total number of applications of any one class of fungicide to two per season.

Educate yourself about fungicide activity, mode of action and class.

Start with a clean house by eliminating resistant isolates via physical and chemical sanitation.

Because there really aren't any manageable ways for growers and packers to change their fungicide practices based on what the other has done or might do (i.e., growers do not consider what packers might use on the harvested crop, nor do packers alter their practices based on what growers have done), a general rule of thumb is to **avoid foliar use of fungicides with related chemistries to any fungicide that potentially might be used in the packinghouse.**

Table 1. Fungicide Cross-Resistance Groups – avoid using these related chemistries both in the field and in the packinghouse.

Citrus

Active Ingredient	Product Name	Fungicide Group*	Pre-harvest Brand in Same Group
Fludioxonil	Graduate	12	None
Thiabendazole	TBZ	1	Topsin-M®
Pyrimethanil	Penbotec™	9	Scala®, Vangard®
Imazalil	Freshgard 700/Pac-Rite® Fungaflor 500C Deccozil® EC 289	3	Enable®

Pome Fruit

Active Ingredient	Product Name	Fungicide Group*	Pre-harvest Brand in Same Group
Fludioxonil	Scholar	12	None
Thiabendazole	Mertect® 340-F/TBZ	1	Topsin-M
Pyrimethanil	Penbotec	9	Scala, Vangard

Stone Fruit

Active Ingredient	Product Name	Fungicide Group*	Pre-harvest Brand in Same Group
Fludioxonil	Scholar	12	None
Fenhexamid	Judge®	17	Elevate®
Pyrimethanil	Penbotec (08/09)	9	Scala, Vangard

**Fungicide groups are designated by FRAC (Fungicide Resistance Action Committee) based on fungicides with similar modes of action or potential for cross-resistance.*

Should we be concerned about the development of resistant isolates of postharvest pathogens for new fungicides?

Let's look at the history of postharvest fungicides for citrus to answer this question (Figure 2). The stories for pome fruit, stone fruit and other crops are similar.

Figure 2. Timelines for fungicide introductions (blue stars) and first reports of resistance development (black bombs) to *Penicillium digitatum* on citrus.

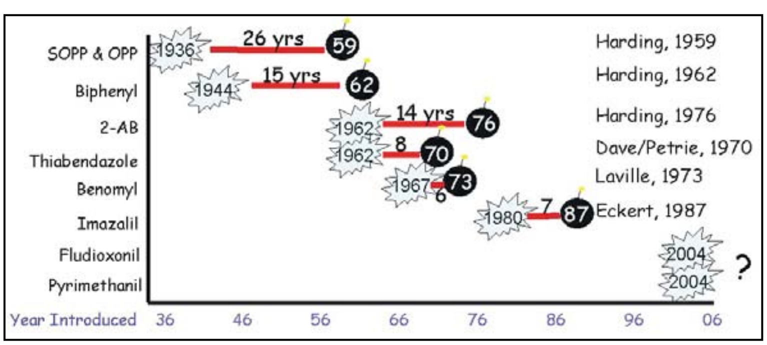


Figure derived from: Kaplan, Dave and Petrie. Proc. Int. Soc. Citriculture. 1981. 788-791

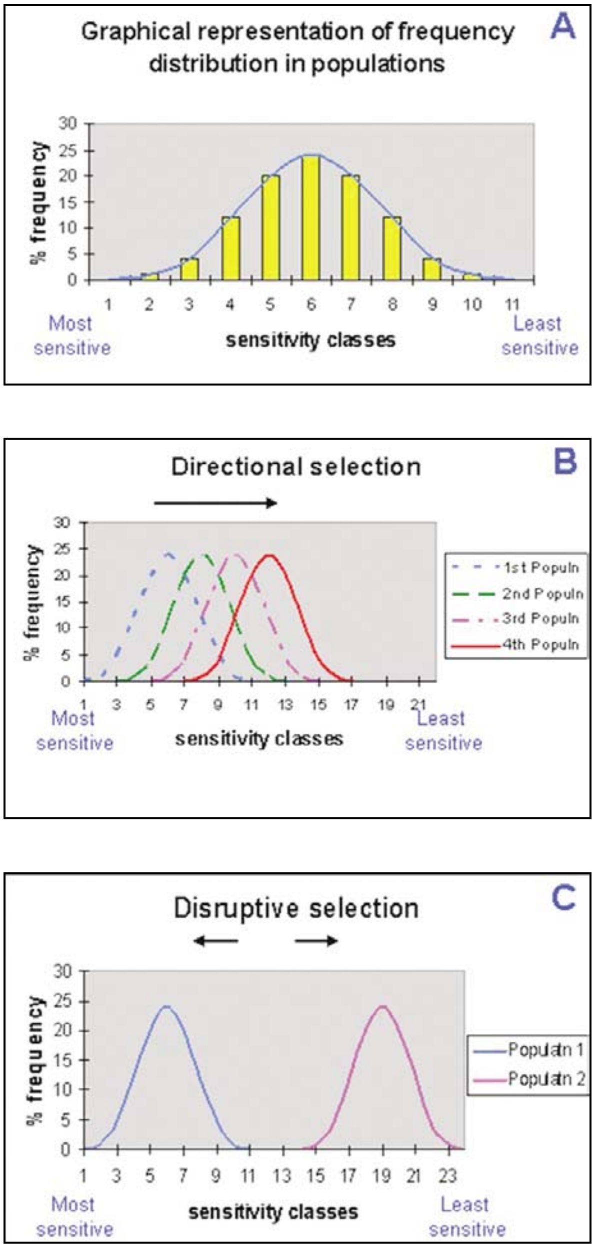
What do we learn from this?

- In over 70 years, only eight fungicides have been developed for postharvest disease control of citrus (including Graduate and Penbotec that were just registered in 2004).
- With exception of the two new fungicides (Graduate and Penbotec), green mold isolates developed resistance to all of the currently registered fungicides.
- Resistance to thiabendazole, benomyl and imazalil developed relatively quickly (within six to eight years).
- History tells us that there is an inherent risk of resistance to fungicides that are applied for postharvest disease control.

How does resistance develop?

Fungicide resistance derives from a change in the fungal pathogen and not due to changes in the fungicide or the host plant. The change in the pathogen from being sensitive to a fungicide to being resistant to it involves a genetic change that is passed on to successive generations. To understand how resistance arises, we must think of the pathogen as a population consisting of mixtures of individuals (strains) with differing levels of sensitivity to the fungicide (Figure 3A). Some strains within the population may be inherently less sensitive and will not be killed by the fungicide. Therefore, an application of fungicide will kill off the sensitive strains while allowing the resistant strains to survive and multiply. Continued use of the same fungicide will shift the population either slowly and directionally to the right (Figure 3B) or in a disruptive manner creating two distinct populations (Figure 3C). The increased number of fungal strains less sensitive or resistant to the fungicide will limit the capability of the product to provide adequate disease control.

Figure 3. Hypothetical depiction of population sensitivity distributions of fungal isolates to a fungicide (A). Illustration of how the fungicide sensitivity of a fungal population can shift either gradually via directional selection (B), or quickly via disruptive selection (C).



Note: Fungicides do not actually cause resistant strains to form because they are not mutagens. Resistant strains arise from a very low natural rate of genetic mutation and are initially present in the population at a very low level.

Before the commercial introduction of a new fungicide, the baseline sensitivity distribution should be established. This means that a number of isolates that have not yet been exposed to the new fungicide are evaluated to see what their baseline sensitivity is. This information helps to establish monitoring studies to determine if changes in sensitivity are occurring after the introduction of the new fungicide. Monitoring indicates whether resistance management strategies need to be adjusted or not. Syngenta and University Cooperators have established the baseline sensitivity of several postharvest pathogens to support resistance management for the new fungicides Graduate and Scholar.

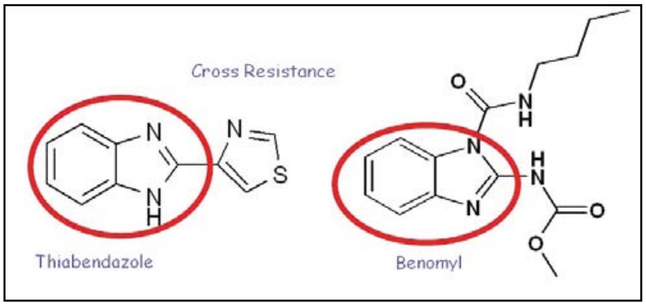
If I stop using the fungicide, will resistance disappear?

This depends on the fungicide and the disease. Often, changes that occur within a fungal strain that confer resistance to the fungicide may reduce the biochemical efficiency compared to sensitive isolates (there is a fitness penalty). In competition with sensitive isolates, these resistant isolates have a fitness disadvantage and are easily out competed by sensitive isolates. However, fungal strains that do not suffer a fitness penalty can remain in the population for some time. The best resistance management strategies to minimize resistant pathogens include: utilizing good sanitization practices in the field and in the packinghouse, not using fungicides with the same mode of action in both the field and the packinghouse, alternating fungicides with a different mode of action, and applying mixtures of fungicides with different modes of action.

Why is the fungicide's mode of action important?

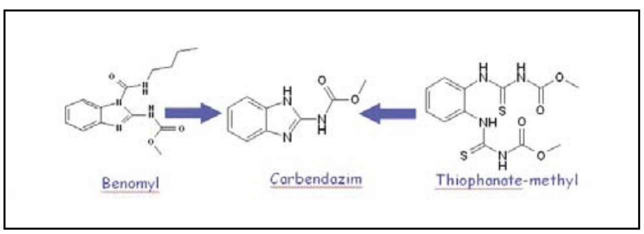
The mode of action of a fungicide is the specific way in which it inhibits the biochemistry of the target fungus. Any genetic change(s) in the fungus that renders it resistant to a fungicide will also render it resistant to other fungicides with the same mode of action. This is referred to as "cross-resistance." Typically, fungicides that are in the same chemistry class have similar chemical structures and similar modes of action, and they are cross-resistant to one another. A classic example is the benzimidazole fungicides. For example, thiabendazole and benomyl are both benzimidazoles. They have similarities in structure (Figure 4), the same mode of action and they are cross-resistant with one another. Therefore, fungal strains that are resistant to one will also be resistant to the other. It is not surprising the first reports of resistance to thiabendazole and benomyl on citrus occurred around the same time (See Figure 2).

Figure 4. Structural similarities of thiabendazole and benomyl fungicides. These fungicides are cross-resistant to one another as well as to all of the other benzimidazoles, thiaphanate-methyl (trade name Topsin-M) and carbendazim.



Understanding fungicide modes of action and cross-resistance is important for the implementation of proper resistance management strategies. There are many examples where common practices of applying fungicides from the benzimidazole chemistry class have led to the development of resistance to other benzimidazoles, like thiabendazole and carbendazim, that were commonly used for postharvest disease control. In fact, when some fungicides, like benomyl or thiophanate-methyl, are added to water, they rapidly convert into the same molecule, carbendazim in this example (Figure 5).

Figure 5. The benzimidazoles benomyl and thiophanate-methyl convert into carbendazim.



Eckert and Wild. 1983. Problems of Fungicide Resistance in Penicillium Rot of Citrus Fruits. In Pest Resistance to Pesticides ed.G.P. Georghiou T. Saito pp. 525-556.

Is it better to alternate between fungicides with different modes of action or to use mixtures for resistance management?

This has been a very confusing topic of international debate for some time. It is not completely clear that one strategy is better or worse than the other. However, both strategies have worked to slow the establishment of resistance to some fungi. The theory behind alternations is demonstrated in Figure 6.

Figure 6. Hypothetical illustration of how alternations can work to reduce the development of resistant strains of fungi. Yellow circles represent sensitive spores and red circles represent resistant spores.

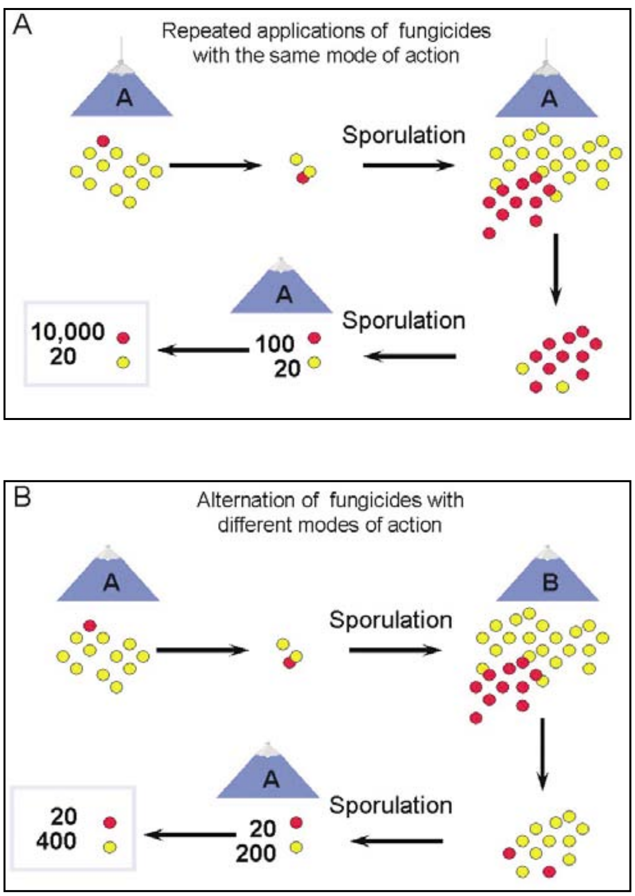
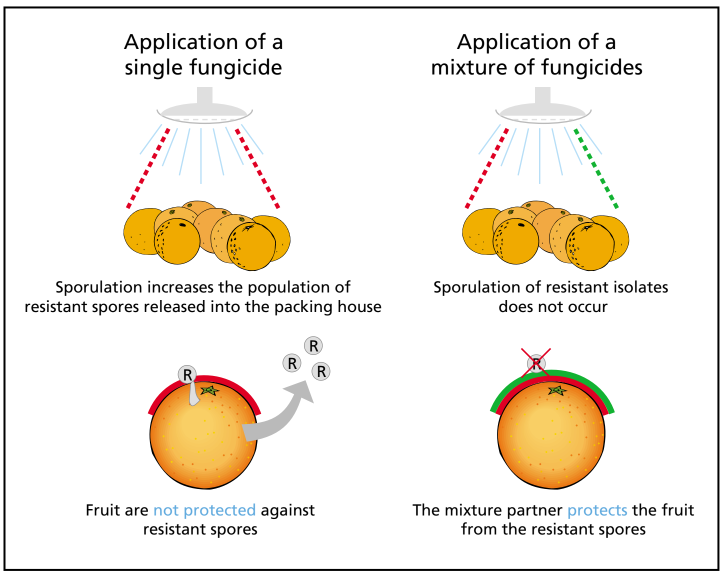


Figure 6A illustrates repeated use of the same fungicide (Fungicide A). Yellow circles represent sensitive spores and red circles represent resistant spores. The first application kills most of the sensitive spores but does not kill the resistant spore. Sporulation rebuilds both populations. However, the second application of the same product again kills the sensitive spores leaving behind the resistant ones. So by the third application, this process has greatly shifted the population toward resistance. In contrast, alternation of two fungicides (Fungicides A and B) with completely different modes of action knocks back the resistant population so that the population is maintained (Figure 6B).

Mixtures also knock back resistant populations and prevent them from sporulating and spreading through the packinghouse (Figure 7).

Figure 7. Hypothetical illustration of how mixtures control resistant fungal populations.



Application of a single fungicide on fruit when isolates resistant to that fungus are present is essentially like not treating the fruit at all; the fruit are not protected from infection. Once infected with the resistant isolate, the fungus is free to sporulate and spread resistant spores throughout the packinghouse. However, mixtures of fungicides with different modes of action (and with activity against the target pathogen of concern) provide protection against those resistant spores. One note of caution is that appropriate rates need to be maintained for this strategy to work. Often, people have the misconception that when using more than one fungicide at a time they can cut the rates. However, if sub-lethal rates of the mixture partners are used, then not only will the treatment most likely fail, but the selection process for isolates resistant to both fungicides will also begin.

Notes:

For references for the material presented in this brochure please visit Syngenta's postharvest web site listed directly below.

For more information please visit www.postharvestuniversity.com or call the Syngenta Customer Resource Center at 1-866-Syngenta.

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