Principles of Fungicide Resistance

Fungi are the cause of many diseases of horticultural crops. Sustainable disease control is best achieved with an integrated management approach. Cultural control practices include crop rotation, time of planting, microclimate modification, and selection of disease-tolerant or disease-resistant cultivars. In many cases, cultural control methods may not be sufficient to effectively manage disease. Fungicides are chemicals that are used to inhibit or suppress fungal growth and are critical to managing plant diseases caused by fungi. However, fungi may develop resistance to fungicides, decreasing the tactics available to growers to effectively manage these diseases.

How does resistance work and why is it a problem?

Applying a fungicide confers a selection pressure on the pathogen population towards resistance development. Resistance development is an evolutionary process. Fungi, like all living organisms, are constantly changing. These changes can help fungi survive in different environmental conditions. Exposure to a fungicide places a “stress” on the population to evolve to overcome the fungicide. Only the “fittest” (i.e. resistant) fungi will survive between growing seasons (Fig. 1). New fungicides may be developed; however, they typically have a similar mode of action (MOA) to those already available. Furthermore, if fungicides are over-used, the rate of resistance can overcome the rate of introducing new MOAs. It is important to extend the use of the current fungicides by using them judiciously and adhering to best practice guidelines to prevent resistance development.

**Resistance:** A decrease in fungal sensitivity due to genetic changes that allow fungi to overcome a specific fungicide.

**Qualitative Resistance:** One genetic change in a specific metabolic pathway confers complete resistance.

**Quantitative Resistance:** One genetic change in a specific metabolic pathway may convey partial resistance and changes in additional genes may be required to confer total resistance.

To best prevent the development of resistance to fungicides, we need to consider the pathogen being targeted and the potential fungicides that can be used for management.

Know your pathogen!

It is important to first identify the pathogen and then consider its characteristics in relation to risk of developing resistance. A pathogen’s life cycle, reproduction method, and genetic diversity can help predict the likelihood of a pathogen developing resistance to a particular fungicide (Fig. 2).

![Diagram showing characteristics of fungal pathogens affecting resistance development]

Know your fungicide!

Fungicides vary in their risk of development dependent upon their mode of action. The risk of resistance development depends on the fungicide’s MOA and application practices. A fungicide can have a specialized MOA targeting a single metabolic pathway in a specific type of microorganism (single-site) (Fig. 3) or a generalized MOA targeting multiple metabolic pathways in a variety of microorganisms (multi-site) (Fig. 4).
Mode of Action

Single-Site
- Specific
- Highly effective
- Targets one specific metabolic process
- Lower environmental impact
- Less toxic to plants
- Higher resistance risk
- Risk of qualitative resistance

Multi-site
- Generalist
- Targets multiple sites within the pathogen
- Potential for non-target organism impact
- Higher environmental impact
- Lower resistance risk
- Risk of quantitative resistance

Treating crops with a mixture of single-site and multi-site fungicides best manages for resistance. Adding in a multi-site fungicide helps to manage for resistance by increasing the probability of killing fungal isolates with decreased sensitivity to single-site MOA fungicides. The number of fungicide applications applied can also affect the probability of resistance development. If multiple and consistent applications are made on the same pathogen population each year, the likelihood of resistance development increases.
The Fungicide Resistance Action Committee (FRAC) assigns a group number to each fungicide based on its MOA. Fungicides with different trade names can be in the same group. For example, Quadris® and Cabrio® are in FRAC group 11, the strobilurin fungicides, which target cellular respiration. In addition, different FRAC groups can target the same fungal metabolic process. For example, SDHI fungicides in FRAC group 7 also target cellular respiration. Isolates resistant to a fungicide with a single-site MOA can also be resistant to other fungicides targeting the same metabolic process, even if the fungi have never been exposed to them. Cross-resistance can occur to products of similar MOA’s or belonging to a common FRAC group.

To reduce risk of resistance development, it is important to follow fungicide label instructions, including the recommended rates and application intervals. Recommended rates are developed to minimize the possibility of resistance.

It is also important to rotate fungicides that target different metabolic processes to delay resistance. This can be achieved by mixing fungicides of different MOAs or alternating the application of products with different MOAs. In general, products with differing FRAC group numbers will differ in their MOA. It is important to note the fungicide FRAC group number when considering the addition of new fungicides for disease management. Multi-site fungicides are designated by a FRAC code that includes the letter “M.”
### Example fungicides commonly used in New York for specialty crops and their risk of resistance development

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Active Ingredient</th>
<th>FRAC Group</th>
<th>Risk of Resistance Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endura®</td>
<td>boscalid</td>
<td>7</td>
<td>Medium to High</td>
</tr>
<tr>
<td>Quadris®</td>
<td>azoxystrobin</td>
<td>11</td>
<td>High</td>
</tr>
<tr>
<td>Cabrio®</td>
<td>pyraclostrobin</td>
<td>11</td>
<td>High</td>
</tr>
<tr>
<td>Tilt®</td>
<td>propiconazole</td>
<td>3</td>
<td>Medium</td>
</tr>
<tr>
<td>Switch®</td>
<td>cyprodinil +fludioxonil</td>
<td>9+12</td>
<td>Medium</td>
</tr>
<tr>
<td>Topsin®</td>
<td>thiophanate-methyl</td>
<td>1</td>
<td>High</td>
</tr>
<tr>
<td>Rovral®</td>
<td>iprodione</td>
<td>2</td>
<td>Medium to High</td>
</tr>
<tr>
<td>Copper Compounds</td>
<td></td>
<td>M1</td>
<td>Low</td>
</tr>
<tr>
<td>Bravo®</td>
<td>chlorothalonil</td>
<td>M5</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Management Practices to Prevent Resistance Development

- Upon using a new fungicide, immediately start utilizing best practice guidelines.
- Follow fungicide labels in choosing application dose.
- Design a program to rotate modes of action.
  - Do not apply more than two consecutive applications of fungicides in the same FRAC group; and
  - Do not apply fungicides in the same FRAC group more than three times in the same season.
- Optimize timing of fungicide applications.
- Use the appropriate adjuvant, nozzles, and volume to ensure adequate coverage of the target tissue.

### For More Information

- [www.frac.info](http://www.frac.info)
- [http://vegetablemdonline.ppath.cornell.edu/NewsArticles/FungicideResistance.html](http://vegetablemdonline.ppath.cornell.edu/NewsArticles/FungicideResistance.html)