Fungicide Basics and Use in Vegetable Disease Management

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Understanding how and when a disease occurs is critical to determining management.
In plant pathology there are three principle components that affect the intensity of disease. However, we must added time to the triangle when we consider disease management recommendations.
For the host it is important to consider: resistance, age and where the disease occurs.
Environment is a key in determining the amount of disease that will be present.

- **Powdery Mildew**: Dry weather
- **Downy Mildew**: Wet weather
We need to know what stage in the pathogens life cycle we are trying to control.

An integrated approach is critical to disease control.

- Crop Rotation
- Tillage
- Weed mngt.
- Assess the risk
Spray recommendations are based on all of these components.

## Watermelon Fungal Spray Program

**Nicholas S. Dufault, Extension Vegetable Plant Pathologist – University of Florida**  
**Mathews L. Paret, Assistant Professor Plant Pathology – University of Florida, NFREC**

Program starts 1 week after transplanting, then use a 7-10 day schedule (especially with weekly rainfall)

<table>
<thead>
<tr>
<th>Spray No.</th>
<th>Fungicide/Product</th>
<th>Notes</th>
</tr>
</thead>
</table>
| 1         | Chlorothalonil (GSB)  
Copper fungicide/Actigard (BFB) | Preventative spray  
Copper used prior to fruit set if BFB is an issue |
| 2         | Chlorothalonil (GSB)  
Copper fungicide/Actigard (BFB) | Preventative spray  
Copper used prior to fruit set if BFB is an issue |
| 3         | Chlorothalonil (GSB)*  
Copper fungicide/Actigard (BFB) | *If disease is present, use a systemic (i.e. Tebuconazole or inspire super) |
| 4         | Chlorothalonil (GSB)*  
Copper fungicide (BFB) | *Preventative spray, but should consider a systemic if there is disease pressure. |
| 5         | Tebuconazole OR Inspire Super (GSB)  
Copper fungicide (BFB) | Luna experience can be added to this rotation once it becomes available for GSB and PM, and Torino for PM. |
| 6         | Mancozeb (GSB + DM)  
Presido or Revus (DM or PCAP)  
Copper fungicide (BFB) | Could spray Cabrio, as well, for Anthracnose control. Remember to watch FRAC and rotate fungicides. Watch for fruit set with copper fungicide spray. |
| 7         | Tebuconazole OR Inspire Super (GSB)  
Quintec or Endura or Procure or Rally (PM) | Luna experience can be added to this rotation once it becomes available for GSB and PM, and Torino for PM. |
| 8         | Mancozeb (GSB + DM)  
Presido or Revus (DM or PCAP) | Managing Gummy Stem Blight  
Managing DM and Phytophthora. |
| 9         | Tebuconazole OR Inspire Super (GSB)  
Topsin+mancozeb OR Inspire Super (GSB + ANTH)  
Presidio or Revus (DM or PCAP) | Luna experience can be added to this rotation once it becomes available for GSB and PM, and Torino for PM. |

- Disease management should be part of an integrated program that uses disease free seed/transplants, proper crop rotation, debris removal and resistant varieties.  
- Cholorothalonil can burn the watermelon rind and sprays should be stopped 21 days before harvest.  
- Actigard and copper fungicides are used to manage BFB before it is a disease issue (i.e. high severity or incidence).  
- As always, fungicide labels should be consulted for rates and application instructions as well as other detailed spray information (PHI, spray limits, etc.).  
- Pay attention to preharvest intervals (PHI) for late season sprays as they may be as high as 14 days.  
- Sprays can be reduced to 14 day intervals in the spring under dry condition (i.e. no rainfall).

**Consult the Vegetable Production Handbook for Florida for more detailed management information.**

**Disease Acronyms:**  
GSB=Gummy Stem Blight; BFB=Bacterial Fruit Blotch; PM=Powdery Mildew; DM=Downy Mildew; ANTH=Anthracnose; PCAP=Phytophthora crown and fruit rot.
How do we know which fungicide to use or recommend in these programs?
For fungicide recommendations you often hear:

- Rotate the mode of action
- Systemic and contact
- FRAC number

What do these terms mean and how are fungicides active in the plant?
What is a fungicide?

3 names: chemical name, common name and trade name

Fungicide: chemical/physical agent that kills/inhibits the growth of fungi

Classified as follows:
1. Mode of action
2. Breadth of activity
3. Mobility within the plant
4. Role in protection
5. Chemical group
6. FRAC Code

D. Mueller, Iowa State Univ.
1. Mode of action

How the fungicide acts on the target fungus, e.g.

- damage cell membranes
- inactivates critical enzymes/proteins
- interferes with respiration
- Microtubules
- Thiophanate-methyl
- Fluopicolide

- Mitochondrion
  - Qol
  - Cyazofamid
  - Boscalid
  - Flutolanil

- Cell wall
  - Polyoxin D

- Nucleic acids
  - Mefenoxam

- General cell constituents
  - Chlorothalonil
  - Sulfur
  - Copper

- Cell membranes
  - DMI
  - Dicarboximides
  - Fludioxonil
  - PCNB
  - Chloroneb
  - Propamocarb

R. Latin, 2011
2. Breadth of activity

Single-site:

• active against only one point in one metabolic pathway in a fungus, OR against a single enzyme or protein needed by the fungus

Multi-site:

• affects a number of different metabolic sites within the fungus
Mitochondria

Fig. 2.7. The respiratory electron transport chain occurs within mitochondria. It generates energy in the form of adenosine triphosphate (ATP) to fuel other cell functions. Two of the four complexes in the chain are targeted by fungicides used for turf disease control. Carboxamide fungicides (boscalid and flutolanil) disrupt electron transport at Complex II. QiI (quinone inside inhibitor) fungicide (cyazofamid) and QoI (quinone outside inhibitor) fungicides (azoxystrobin, fluoxastrobin, pyraclostrobin, and trifloxystrobin) interrupt the chain at Complex III.
Cytoplasm

Fig. 2.8. Target site of demethylation inhibitors (DMI fungicides).
3. Mobility within the plant

Contact

Droplets spread out and remain on the surface where applied; do not move inside.

Leaves produced after the application are not protected.

No chemical = no protection.

D. Mueller, Iowa State Univ.
3. Mobility within the plant

Systemic:
(i) Locally / translaminar

Leaves produced after the application are not protected
No chemical = no protection

Droplets spread out and are absorbed by plant tissue

D. Mueller, Iowa State Univ.
3. Mobility within the plant

Systemic:
(ii) acropetal

Leaves produced after the application MAY be protected

No chemical = rely on fungicide via xylem

Droplets spread out and are absorbed by leaf tissue. Fungicide moves upwards in the xylem to edge of leaves and new growth

D. Mueller, Iowa State Univ.
<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Phytomobility classification</th>
<th>Movement throughout the plant</th>
<th>Movement among cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>chlorothalonil</td>
<td>Contact</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>mancozeb</td>
<td>Contact</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>thiram</td>
<td>Contact</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>PCNB</td>
<td>Contact</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>chloroneb</td>
<td>Contact</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>etridiazole</td>
<td>Contact</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>iprodione</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Uncertain</td>
</tr>
<tr>
<td>vinclozolin</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Uncertain</td>
</tr>
<tr>
<td>trifloxystrobin</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>pyraclostrobin</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>cyazofamid</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>fludioxonil</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>polyoxin D</td>
<td>Local penetrant</td>
<td>Translaminar</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>azoxystrobin</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>fluoxastrobin</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>fenarimol</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>metconazole</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>myclobutanil</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>propiconazole</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>tebuconazole</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>triadimefon</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
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<tr>
<td>triticonazole</td>
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<td>Xylem mobile</td>
<td>Apoplastic</td>
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<td>flutolanil</td>
<td>Acropetal penetrant</td>
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<td>Apoplastic</td>
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<td>boscalid</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>mefenoxam</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>thiophanate-methyl</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>propamocarb</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>flupicolide</td>
<td>Acropetal penetrant</td>
<td>Xylem mobile</td>
<td>Apoplastic</td>
</tr>
<tr>
<td>fosetyl aluminum</td>
<td>Systemic penetrant</td>
<td>Ambimobile</td>
<td>Symplastic</td>
</tr>
<tr>
<td>phosphonic acids</td>
<td>Systemic penetrant</td>
<td>Ambimobile</td>
<td>Symplastic</td>
</tr>
</tbody>
</table>
4. Role in protection

Preventative:
- acts as a protective barrier
- prevents spore germination and infection
- contact and systemic fungicides

Early infection (“curative”) activity:
- systemic
- stops pathogen in plant tissues (24-72h after infection)
- most effective when applied before infection
4. Role in protection

**Eradication:**
- stop disease development after symptoms developed
- VERY FEW fungicides

**Anti-sporulant activity:**
- prevent spores being produced
- disease continues to develop
A visual depiction of fungicide’s role in protection.

Figure 7.1. Schematic representation of fungicide activity in relation to soybean rust development.

5. Chemical groups

- A group of chemicals that share a common biochemical mode of action
- May / may not have similar chemical structure
  - Demethylation Inhibitor (DMI) (includes triazoles)
  - QoI (includes strobilurins)
  - Methyl Benzimidazole Carbamates (MBC)
  - Carboxamides
  - Chloronitriles
QoI fungicides

Examples:

- azoxystrobin (Quadris®)
- pyraclostrobin (Headline®)
- trifloxystrobin (Stratego YLD®)
- fluoxastrobin (Evito®)

- **single site activity** – quinol outer binding site of cytochrome bc1 complex
Qol fungicides

• **Mode of action:**
  - prevent energy production by the fungus by inhibiting mitochondria respiration
  - Stop spore germination and early mycelium growth (infection)

• **Role in protection:** Preventative / early infection activity

• **Other information:**
  - Residual period up to 21 days
  - mostly locally systemic (translaminar)*
  - prone to resistance

*Two strobilurin fungicides currently on the marketplace can move thru the xylem (azoxystrobin (a.i. in Quadris – or one of the a.i.s in Quilt and Quilt Xcel) and fluoxastrobin (Evito).

D. Mueller, Iowa State Univ.
1. Surface redistribution
2. Penetrate waxy cuticle
3. Translaminar activity
4. Vapor movement & reabsorption

Adapted from: Vincelli, 2002
http://www.apsnet.org/

D. Mueller, Iowa State Univ.
Fig. 1.8. Movement of acropetal and local penetrant fungicides. Fungicides were applied to the bases of wheat leaves prior to inoculation with the powdery mildew pathogen. (Adapted from Bartlett et al., 2002)
Triazole fungicides

Demethylation Inhibitor (DMI) fungicides

Examples:

- tebuconazole (TebuStar, Monsoon)
- propiconazole (Tilt®, Quilt, Quadris Xtra)
- prothioconazole (Proline®)
- metconazole (e.g., Headline Amp®)
- tetraconazole (Domark®)

- single site activity – inhibit C14-demethylase

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Triazole fungicides

- **Mode of action:**
  - prevent sterol production by the fungus
  - sterols = building blocks of membranes
  - result in abnormal fungal growth and eventual death

- **Role in protection:** preventative / early infection activity / anti-sporulant

- **Other information:**
  - Residual period ~ 14 days
  - locally systemic (typically more mobile than QoI fungicides)
  - prone to resistance

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Triazole fungicides

- Mobility

1. Moves into epidermis
2. Rapidly penetrates leaf tissue
3. Transported in vascular system
4. Lateral diffusion

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SDHI fungicides

Succinate Dehydrogenase Inhibitor (SDHI) Fungicides

Mode of action: SDHI fungicides inhibit fungal respiration (similar to QoI fungicides).

Mobility in plants: Locally systemic. Movement is translaminar and upward.
The classes of fungicide will affect fungal types differently.
A example of how to use fungicide classes to control a fungus.
A summary comparison of a contact versus penetrant fungicides.

<table>
<thead>
<tr>
<th>Contact</th>
<th>Penetrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Must be applied before infection</td>
<td>Applied soon after infection</td>
</tr>
<tr>
<td>Prevents spore germination</td>
<td>Ineffective once fungus begins reproduction</td>
</tr>
<tr>
<td>No effect after infection</td>
<td>Limited “curative” effect</td>
</tr>
<tr>
<td>Low risk for resistance</td>
<td>Higher risk for resistance</td>
</tr>
</tbody>
</table>

Remember common penetrant movement:
- Translaminar
- Acropetal

6. FRAC code

- The FRAC code represents the mode of action of the fungicide.
- Alternate numbers to manage fungicide resistance
Fungicide resistance

- Resistance risk varies by pathogen and fungicide class
  - DMI (triazole; FRAC 3) – Medium Risk – slower, more gradual development
  - SDHI (FRAC 7) – Medium Risk – > 10 mutations
  - QoI (Strobilurin; FRAC 11) – High Risk – One common mutation (G143A) but others have been detected
    - Some pathogens will not survive the G143A mutation (lower risk)

- Resistance management strategies
  - Good agronomic practices
  - Restriction in spray number
  - Use of a diversity of fungicide modes of action

http://www.frac.info/index.htm
FRAC # are a simple way to know which fungicide you are using.

![](image.jpg)

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Active Ingredient</th>
<th>Group (FRAC)</th>
<th>Type</th>
<th>Target Pest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bravo, Echo, etc</td>
<td>chlorothalonil</td>
<td>M</td>
<td>C</td>
<td>GSB, DM, PM</td>
</tr>
<tr>
<td>Dithane, Penncozeb, etc.</td>
<td>mancozeb</td>
<td>M</td>
<td>C</td>
<td>GSB, DM</td>
</tr>
<tr>
<td>Champ, Kocide, etc.</td>
<td>copper hydroxide</td>
<td>M</td>
<td>C</td>
<td>BFB</td>
</tr>
<tr>
<td>Totsin M</td>
<td>thiophanate-methyl</td>
<td>1</td>
<td>S</td>
<td>ANTH</td>
</tr>
<tr>
<td>Folicur, Tebuzeole, etc.</td>
<td>tebuconazole</td>
<td>3</td>
<td>S</td>
<td>GSB, PM</td>
</tr>
<tr>
<td>Procure</td>
<td>triflumizole</td>
<td>3</td>
<td>S</td>
<td>PM</td>
</tr>
<tr>
<td>Rally</td>
<td>myclobutanil</td>
<td>3</td>
<td>S</td>
<td>PM</td>
</tr>
<tr>
<td>Endura</td>
<td>bosalid</td>
<td>7</td>
<td>S</td>
<td>PM</td>
</tr>
<tr>
<td>Pristine</td>
<td>bosalid + pyraclostrobin</td>
<td>7 + 11</td>
<td>S</td>
<td>GSB, DM, PM</td>
</tr>
<tr>
<td>Inspire Super</td>
<td>cyprodinil + difenoconazole</td>
<td>9 + 3</td>
<td>S</td>
<td>GSB, PM</td>
</tr>
<tr>
<td>Switch</td>
<td>cyprodinil + fludioxonil</td>
<td>9 + 12</td>
<td>S + C</td>
<td>GSB, PM</td>
</tr>
<tr>
<td>Cabrio</td>
<td>pyraclostrobin</td>
<td>11</td>
<td>S</td>
<td>ANTH</td>
</tr>
<tr>
<td>Quintec</td>
<td>quinoxyletin</td>
<td>13</td>
<td>C</td>
<td>PM</td>
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<td>Ranman</td>
<td>cyazofamid</td>
<td>21</td>
<td>S</td>
<td>DM</td>
</tr>
<tr>
<td>Previcur Flex</td>
<td>propamocarb</td>
<td>28</td>
<td>S</td>
<td>DM</td>
</tr>
<tr>
<td>Revus</td>
<td>mandipropamid</td>
<td>40</td>
<td>S</td>
<td>DM</td>
</tr>
<tr>
<td>Presidio</td>
<td>fluopicolide</td>
<td>43</td>
<td>S</td>
<td>DM</td>
</tr>
</tbody>
</table>

**FUTURE PRODUCTS**

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Active Ingredient</th>
<th>Group (FRAC)</th>
<th>Type</th>
<th>Target Pest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luna Experience (Bayer)</td>
<td>Tebuconazole + Fluopyram</td>
<td>3 + 7</td>
<td>S</td>
<td>GSB, PM</td>
</tr>
<tr>
<td>Torino (Gowan Co.)</td>
<td>Cyfluifenamid</td>
<td>U6</td>
<td>PM</td>
<td></td>
</tr>
</tbody>
</table>

In general, fungicides either stay where you apply them or move up!

Fungicide deposits in the leaf axil near emerging leaves may provide protection for new leaves.

Fungicides that reach thatch and soil may be absorbed by roots.

A fungicide deposit close to the crown will protect the oldest leaf sheath from infection, but will not provide protection to new leaves.
Key spray factors for disease control with fungicides are:

- **Application rates** vary from 15 to 100 GPA
  - Range of rates specified on label
  - Higher rates often better coverage
- **Spray intervals** vary from 7 to 21 days
  - Fungicides breakdown
  - Environment
- **Surface coverage** (spray nozzle type and droplet size)
Spray intervals are based on fungicide residual or plant growth.
Complete coverage (100%) is impossible.

• How much do we need to cover?
  – Late blight: yield increases at 28% coverage
  – Foliar disease can be tolerated
    • Corn: upper 1/3 canopy coverage
    • Legumes: upper 1/3 or so canopy coverage

• Ornamentals and turf more extensive coverage.
Droplet sizes from 200 to 300 microns are best for fungicide applications.

### Table 1. Droplet size categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>Symbol</th>
<th>Color code</th>
<th>Approximate VMD (0.5) (microns)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very fine</td>
<td>VF</td>
<td>red</td>
<td>&lt;150</td>
</tr>
<tr>
<td>Fine</td>
<td>F</td>
<td>orange</td>
<td>150-250</td>
</tr>
<tr>
<td>Medium</td>
<td>M</td>
<td>yellow</td>
<td>250-350</td>
</tr>
<tr>
<td>Coarse</td>
<td>C</td>
<td>blue</td>
<td>350-450</td>
</tr>
<tr>
<td>Very coarse</td>
<td>VC</td>
<td>green</td>
<td>450-550</td>
</tr>
<tr>
<td>Extremely coarse</td>
<td>XC</td>
<td>white</td>
<td>&gt;550</td>
</tr>
</tbody>
</table>

*VMD (volume mean diameter) = droplet size where half of the volume has droplets greater than the volume mean diameter, and half the volume has droplets smaller than the volume mean diameter.

Drift is a worry (avoid herbicide mixing)
Common nozzles used for fungicides

- Twin Jet Flat Fan
- Flat Fan
- Hollow Cone or Whirling Disc
- Air Induction Flat Fan
Canopy density important in determining coverage from a nozzle.

T. Mueller (soybeans), 2006
Fungicide coverage might be less important when using a penetrant.

Tebuconazole (penetrant) sprays

T. Mueller, 2007
Spray coverage is important, but it is important to consider the goal.

- If it is a preventative (contact) spray than coverage is critical.
- If it is a responsive (penetrant) spray then coverage maybe less critical.

The basics of a “good” spray program

- **Prevention is key!**

- Be sure to **rotate chemistries**
  - FRAC number
  - Labels for details

- Fungicides will manage diseases, but will not eliminate them.
Questions?

Thank you to Dr. Daren Mueller