Management of Brown Rot of Stone Fruit Crops in California

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“Brown rot is a major fungal disease of all commercially grown Prunus species in most regions of the world and can result in extensive crop losses.” (Battra, 1991)

“It is the primary disease for which fungicides are applied to stone fruits.” (D. Ritchie, North Carolina State University)
Brown rot of peach

Blossom blight and twig cankers

Preharvest fruit decay

Postharvest fruit decay
Brown rot of prune and apricot

Blossom blight

Preharvest fruit decay
Brown rot of sweet cherry

Blossom blight

Preharvest fruit decay

Postharvest fruit decay
Brown rot of stone fruits - Pathogens

- Main pathogens: *Monilinia fructicola*, *M. laxa*, *M. fructigena*
- *M. fructicola* and *M. laxa* are the most destructive on stone fruit
- **New species** reported from China in 2010/11: *M. polystroma*, *M. mumecola*, *M. yunnanensis*.

![Map showing the historic geographic range of the main three brown rot pathogens (Batra, 1991)]
Brown rot of stone fruits - Pathogens

• Main pathogens: *Monilinia fructicola, M. laxa, M. fructigena*

• Cultural identification on PDA:

![Images of *M. laxa*, *M. fructicolata*, and *M. fructigena* on PDA]
Brown rot of stone fruits - Pathogens

Main pathogens: *Monilinia fructicola, M. laxa, M. fructigena*

- *M. fructicola* has been a quarantine pest in Europe, but since 2001 has been found at locations in France, Austria, Spain, the Czech Republic, Italy, Germany, and Switzerland, presumably by way of imported fruit.
- *M. fructicola* is also a new occurrence in Chile.

Current geographic range of the main three brown rot pathogens (Batra, 1991)
Brown rot pathogens of stone fruits in California

• **Blossom blight**
  - **Northern growing areas**
    - Prunes, almonds: mostly *M. laxa*
    - Peaches: *M. fructicola/M. laxa*
  - **Southern growing areas**
    - Peaches, nectarines, plums, sweet cherry: mostly *M. fructicola*
    - Almonds: *M. fructicola, M. laxa*

• **Fruit rot**
  - All crops (except almond): mostly *M. fructicola*
Brown rot of stone fruits – Identification of pathogens

Main pathogens: *Monilinia fructicola, M. laxa, M. fructigena*

- The 3 species are often difficult to differentiate morphologically, but several species-specific primers have been published that can be used in identification and detection of the pathogen.

Specificity of primers developed from ribosomal DNA sequences. A non-specific DNA band is present in all isolates and serves as an internal standard. (Forster and Adaskaveg, 1999).
Disease cycle of *Monilinia* species on peach

- Twig blight and rot of immature and mature fruit
- Overwintering mummy on ground
- Conidia
- Conidia
- Overwintering mummy on tree
- Blossom blight
- Gumming
- Asci
- Ascus & ascospores
- Apothecia
- Apothecium cross section

Sexual cycle *M. fructicola* only
**M. fructicola and M. laxa**
- Reproductive modes -

- Evidence of sexual reproduction in *M. fructicola*, but not in *M. laxa* – molecular diversity among isolates based on RAPD analysis.
- Sexual reproduction creates new gene combinations that may be more adapted to new environments and that are propagated by asexual reproduction.
- Sexual reproduction adds to another survival mechanism.

RAPD analysis of California isolates of *M. fructicola* and *M. laxa* (Forster and Adaskaveg, 1999).
Brown rot of stone fruits
- Infection -

**Infection**

- Direct penetration through the host cuticle
- Indirect penetration through injuries or natural openings (stomata)

J. E. Adaskaveg
Brown rot of stone fruits - Infection

Quiescent infections

• Infections may remain quiescent (latent) and be activated when fruit mature or when environmental conditions become more favorable.

• Quiescent infection may be visible (see image below) or non-visible.

• The presence of quiescent infections can explain sudden increases in fruit decay just before harvest.

Visible quiescent infections on Rainier cherry after inoculation with *M. fructicola* with a 6-h wetness period (Adaskaveg and Forster 1999)
- The Disease Triangle of Plant Pathology -

**Host**
- Varietal susceptibility,
- Planting design

**Environment**
- Wetness - rainfall, irrigation
- Temperatures above 58F

**Pathogen**
- *M. fructicola*, *M. laxa*
- Inoculum potential (overwintering mummies, twig cankers)

The interactions between the components effect the amount of disease.
Brown rot of stone fruits - Epidemiology

Host phenology

• Susceptibility to infection is high during early fruit development, decreases during green fruit stages, and increases again as fruit mature and ripen.

Great differences in **varietal susceptibility**

Seasonal susceptibility of peach fruit to brown rot infection (Biggs et al., 1988)
Simulated rain was applied on 2-10, 2-24, and 2-28-2005. Blossom blight was evaluated on 4-8-04 and on 3-31-05. There were three single-tree replications for each cultivar.
Brown rot susceptibility of peach cultivars within the three-week ripening period before harvest

**Majority of peach cultivars are susceptible to brown rot.**

<table>
<thead>
<tr>
<th>High Pressure</th>
<th>Moderate Pressure</th>
<th>Low Pressure</th>
<th>Very Low Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baby Gold 5</td>
<td>Catherina</td>
<td>Allstar</td>
<td>Hale Harrison</td>
</tr>
<tr>
<td>Early Red Haven</td>
<td>Redhaven</td>
<td>Blazingstar</td>
<td>Halehaven</td>
</tr>
<tr>
<td>Elberta</td>
<td>Vinegold</td>
<td>Blushingstar</td>
<td>Maybelle</td>
</tr>
<tr>
<td>Garnet Beauty</td>
<td>Virgil</td>
<td>Bounty</td>
<td>Mayflower</td>
</tr>
<tr>
<td>Glohaven</td>
<td>Vivid</td>
<td>Brighton</td>
<td>Redbird</td>
</tr>
<tr>
<td>Harbrite</td>
<td>Vulcan</td>
<td>Coralstar</td>
<td>Southhaven</td>
</tr>
<tr>
<td>Harken</td>
<td></td>
<td>Cresthaven</td>
<td>Summercrest</td>
</tr>
<tr>
<td>Harrow Beauty</td>
<td></td>
<td>Dixired</td>
<td></td>
</tr>
<tr>
<td>Harson</td>
<td></td>
<td>Glowingstar</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Redstar</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rising star</td>
<td></td>
</tr>
</tbody>
</table>

Modified from Biggs et al. 1995
Brown rot of stone fruits - Epidemiology

Environment

Temperature requirements:

• Conidial germination occurs over a wide temperature range from 0-30°C
  • Optimum: 20-25°C
• Infections can occur over a wide range
  • Optimum: 22.5-25°C
  • Range: 4-32°C
Brown rot of stone fruits - Epidemiology

Environment

Wetness requirements

- **Conidial germination** - 4 h of wetness at 20° C (68° F)
- **Blossom and fruit infection**
  - 7 h of wetness at 20° C (68° F) to
  - 18 h of wetness at 10° C (50° F) (cherry & peach/nectarine)

Effect of wetness duration on incidence of latent infections on prune fruit under field conditions (Michailides et al., 2007)
Brown rot of stone fruits - Epidemiology

Environment

• **Areas with high rainfall:**
  • Severe epidemics may occur in most years.

• **More arid locations:**
  • Favorable environmental conditions commonly occur in the spring for development of blossom blight.
  • During the season orchard irrigation contributes to sufficient wetness. Occasional rains can be highly destructive.
Brown rot of stone fruits - Epidemiology

Blossom blight and twig cankers

Inoculum production for fruit infections

Preharvest fruit decay

Inoculum production for infection of other fruit

Increase of inoculum over the growing season if the disease is not managed

Late-season fruit is usually more affected than early-season fruit
Stromatized mummies in partial contact with soil produce apothecia: 
a) 2C for 8 weeks at >97%RH;  
b) 12-20C for 2 weeks, under a 12 h photoperiod
Components of an integrated disease management program for brown rot of stone fruit

- Early disease detection
- **Planting**
  - Variety selection (host resistance)
  - Plant spacing (greater air movement, shorter drying period)
  - Row orientation – direction of prevailing winds
- **Cultural practices**
  - Avoid high-angle sprinkler irrigation
  - Provide a balanced nutrition
  - Pruning practices (improved microclimate, removal of diseased tissue)
- **Sanitation**
  - At harvest remove all fruit from trees
  - Remove overwintering mummies from trees and cultivate mummies into soil
- **Chemical control and pest management**
  - Fungicides and insect management (SWD, OFM, PTB, etc.)
Disease cycle of *Monilinia* species on peach

Twig blight and rot of immature and mature fruit

Overwintering mummy on ground

Sanitation

Overwintering mummy on tree

Blossom blight

Host resistance & protection with fungicides

Sexual cycle *M. fructicola* only
Orchard sanitation: Removal of overwintering fruit mummies and soil cultivation

Mummies are primary inoculum sources in the spring. A) On the tree, asexual conidia; B) On the ground, sexual ascospores

Complete harvests and mummy removal from tree

Destroy mummies on the ground by mowing or disking
Brown rot management with fungicides

- Protective fungicide **field treatments** that are properly applied and timed provide the best control for
  - *Blossom blight*
  - *Fruit rot*

- **Postharvest treatments** can protect fruit from infections that occur at harvest and during transport and may prevent the activation of quiescent infections and the establishment of new infections.
Fungicides Registered and in Development for Managing Stone Fruit Diseases in the United States

### Single-fungicides - Inorganics and Conventional Synthetics

**Inorganics**
- Copper, Sulfur
- Captan (1960s)

**Phthalimides**
- Bravo, Echo, Equus (1960s)
- Botran (1960s)

**Isophthalonitriles**
- Elite/Tebuzol, Indar, Rally, Tilt, Topguard, Quash, Inspire*

**Sterol inhibitors (DMIs)**
-pyraclostrobin, picoxystrobin
- Abound, Gem

**Phthalimides**
- Rovral, Iprodione, Meteor, Nevado (1980s)

**Dicarboximides**
- Topsin-M, T-Methyl (1970s)
- T-Methyl

**Benzimidazoles**
- Luna Privilege, Xemium, Fontelis (1960s)
- Rovral, Iprodione, Meteor, Nevado (1980s)

**SDHIs**
- Elite/Tebuzol, Indar, Rally, Tilt, Topguard, Quash, Inspire*
- Luna Privilege, Xemium, Fontelis (1960s)

**Dicarboximides**
- T-Methyl

### Other Classes

**Anilinopyrimidines**
- Vangard, Scala (1990s)

**Qols**
- Abound, Gem, pyraclostrobin, picoxystrobin (1990s)

**Polyoxins**
- Ph-D, Oso (1960s)

**Hydroxyanilides**
- Elevate (1990s)

**SDHIs**
- Luna Privilege, Xemium, Fontelis (1960s)

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**FRAC (Fungicide Resistance Action Committee) Group**
- Single-site mode of action
- Reduced risk fungicides
- Multi-site mode of action
Fungicides for Management of Brown Rot of Stone Fruits in the field in the US

Single-fungicides - Inorganics and Conventional Synthetics

Benzimidazoles
- Topsin-M, T-Methyl
  - 1970s

Dicarboximides
- Rovral, Iprodione, Nevado
  - 1980s

Sterol inhibitors (DMIs)
- Elite, Indar, Inspire, Tilt, Procure, Quash, Rally, Rubigan, Topguard
  - 1970s – 1980s

SDHIs
- Endura, Luna Privilege, Xemium, Fontelis
  - 1960s

Qols
- Abound, Gem, picoxystrobin, Cabrio
  - 1990s

Hydroxyanilides
- Elevate
  - 1990s

Polyoxins
- Ph-D, Oso
  - 1960s

FRAC group (mode of action class) – all have a single-site mode of action

Reduced risk fungicides

Information available at: Statewide IPM Program - www.ipm.ucdavis.edu
Fungicides for Management of Brown Rot of Stone Fruits in the Field in the United States

Conventional Synthetic Fungicides – Pre-mixtures

- Inspire Super
- Luna Experience
- Quadris Top, Quilt Xcel
- Pristine, Luna Sensation, Merivon, Q8Y78

Natural Products and Biocontrols for Managing Stone Fruit Diseases

- Actinovate, Regalia, polyoxin-D, BotryZen, Serenate Optimum, Fracture

Natural products and biocontrols for organic production
Polyoxin-D recently received an exempt status in the United States
Efficacy and Timing of Fungicides, Bactericides, and Biologicals for Deciduous Tree Fruit, Nut, Strawberry, and Vine Crops 2013

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UC Davis, Dept. of Plant Pathology
www.plpnem.ucdavis.edu

UC Kearney Agricultural Center
www.uckac.edu/plantpath

Statewide IPM Program
www.ipm.ucdavis.edu

Efficacy tables are updated annually
Chemical disease control

- There is an increasing arsenal of fungicides being introduced.
- Using the proper material is becoming more difficult and requires an increasing knowledge on the modes of action (fungicide classes), spectrum of activity, efficacy, and best usage strategies.
- Generic compounds can lower the cost.
- Selecting the best materials with the broadest spectrum and timing the application at a critical stage can lower costs.
- Rate and formulation are critical -
  - Use middle to high label rate
  - Formulation rating: AQ < WG < WP < SC < EC
Management of Brown Rot Blossom Blight
Management of brown rot blossom blight in field trials

<table>
<thead>
<tr>
<th>Program</th>
<th>Treatment</th>
<th>Rate/A</th>
<th>60-70% bloom</th>
<th>Number of infections/tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>----</td>
<td>Control</td>
<td>----</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological</td>
<td>Fracture</td>
<td>36.6 fl oz</td>
<td>@</td>
<td>b</td>
</tr>
<tr>
<td>Single</td>
<td>Quash 50WG</td>
<td>3.0 oz</td>
<td>@</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>Mettle</td>
<td>8 fl oz</td>
<td>@</td>
<td>cd</td>
</tr>
<tr>
<td></td>
<td>TopGuard</td>
<td>7 fl oz</td>
<td>@</td>
<td>cd</td>
</tr>
<tr>
<td></td>
<td>Fontelis + NIS</td>
<td>14 fl oz</td>
<td>@</td>
<td></td>
</tr>
<tr>
<td>Pre-mixtures</td>
<td>Luna Sensation</td>
<td>5 fl oz</td>
<td>@</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>Inspire Super + NIS</td>
<td>20 fl oz</td>
<td>@</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>Quadris Top</td>
<td>14 fl oz</td>
<td>@</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>Pristine 38WG</td>
<td>14.5 oz</td>
<td>@</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>Merivon</td>
<td>6.5 fl oz</td>
<td>@</td>
<td>d</td>
</tr>
</tbody>
</table>

Treatments were applied using an air-blast sprayer at a rate of 100 gal/A. Evaluation was done on 5-16-12.
Post-infection activity laboratory tests for fungicides against brown rot blossom blight of sweet cherry

Control
Merivon
Luna Sensation

Full bloom treatment 1 day after inoculation with *M. fructicola*

Test is done under highly favorable disease conditions (high inoculum, wetness).
Pre- and post-infection activity of fungicides against brown rot blossom blight of peach

Protective action: One application of each treatment was made in the field at full boom using an air-blast sprayer (100 gal/A). Blossoms were collected the same day and inoculated in the laboratory with *M. fructicola.*

Postinfection activity: blossoms were inoculated in the laboratory and then treated after 2 days. Blossoms were evaluated after 4 to 5 days at 20C.
Timing of fungicide treatments for management of brown rot blossom blight

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>3-3-11 30% bloom</th>
<th>3-9-11 50-60% bloom</th>
<th>Incidence of blight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>---</td>
<td>---</td>
<td>a</td>
</tr>
<tr>
<td>Quash 50WG 3.5 oz</td>
<td>@</td>
<td>@</td>
<td>b</td>
</tr>
<tr>
<td>Control</td>
<td>---</td>
<td>---</td>
<td>a</td>
</tr>
<tr>
<td>Vangard 75WG 5 oz</td>
<td>@</td>
<td>@</td>
<td>b</td>
</tr>
<tr>
<td>Control</td>
<td>---</td>
<td>---</td>
<td>a</td>
</tr>
<tr>
<td>Tilt (Orbit) 4 fl oz</td>
<td>@</td>
<td>@</td>
<td>b</td>
</tr>
</tbody>
</table>

Incidence of blight (%)

cv. Summer Fire nectarine –

High rainfall conditions.

All fungicides used have some systemic activity.
Blossom blight control with fungicides under conducive and less conducive conditions for disease

One application of each treatment was made on 3/4/04 using an air-blast sprayer (100 gal/A) to Red Diamond nectarines (35% bloom), Elegant Lady peach (20% bloom), and to Fairtime peach (1-5% bloom). Simulated rain treatments (8 h each) were done on 3/5 and 3/8. Blossoms were evaluated for blossom blight after 5 weeks.


## Considerations for timing of bloom applications

<table>
<thead>
<tr>
<th>Determining factors</th>
<th>WT or FB or DB</th>
<th>WT and FB application</th>
<th>WT, FB, &amp;PF application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental conditions (rain)</td>
<td>Less favorable</td>
<td>Favorable</td>
<td>Highly Favorable</td>
</tr>
<tr>
<td>Fungicide properties</td>
<td>Locally systemic action</td>
<td>Contact or locally systemic action</td>
<td>Contact or locally systemic action</td>
</tr>
</tbody>
</table>

WT = White tip (5% bloom)  
FB = Full bloom (80% bloom)  
Delayed bloom (DB) = 20-40% bloom
Blossom blight control with fungicides

<table>
<thead>
<tr>
<th>Univ. of California guidelines</th>
<th>Delayed bloom application</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 applications during bloom</td>
<td>1 application at 30-50% bloom</td>
</tr>
</tbody>
</table>

- Use when environmental conditions are highly favorable (rain)
- Use when environmental conditions are less favorable

Models that have been developed to predict the need of a fungicide application are considered not economical due to the low cost of a fungicide spray and the high risk for crop losses.
Brown rot management using preharvest fungicide applications
Preharvest treatments for management of brown rot

1 preharvest application 1 – 10 days before harvest
Preharvest fungicide treatments for managing brown rot fruit decay in field trials - 2012

Early maturing stone fruit cultivars

<table>
<thead>
<tr>
<th>Single fungicide</th>
<th>July Flame peach 7 days PHI</th>
<th>Summer Flare nect. 7 days PHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Quash 50WG 3 oz</td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>Luna Sensation 500SC 5 fl oz</td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>Luna Experience 8 fl oz</td>
<td>bc</td>
<td>b</td>
</tr>
<tr>
<td>Inspire Super + NIS 20 fl oz</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>Quadris Top 14 fl oz</td>
<td>bc</td>
<td>b</td>
</tr>
<tr>
<td>Pristine 38WG 14.5 oz</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>Merivon 6.5 fl oz</td>
<td>bc</td>
<td>b</td>
</tr>
</tbody>
</table>

Incidence of brown rot decay (%)

- Numerous highly effective fungicides are available
- **Single applications** are best applied within 8 days of harvest, whereas treatments in a **two-spray program** should be done at a 7- to 10-day interval within two weeks of harvest.
Late maturing stone fruit cultivars

- Late-maturing varieties benefit from two preharvest applications due to an increased inoculum level in the orchard and higher decay potential.
## Efficacy of selected fungicides for control of common in-season diseases of stonefruit*

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Common Name</th>
<th>Brown Rot</th>
<th>Gray Mold</th>
<th>Powdery Mildew</th>
<th>Rust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rovral 50WP</td>
<td>Iprodione</td>
<td>+++ (BB)</td>
<td>+++</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Elite 45WP</td>
<td>Tebuconazole</td>
<td>++++</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Orbit 3.6EC</td>
<td>Propiconazole</td>
<td>++++</td>
<td>-</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Indar 75WSP</td>
<td>Fenbuconazole</td>
<td>++++</td>
<td>-</td>
<td>++</td>
<td>?</td>
</tr>
<tr>
<td>Rally 40WP</td>
<td>Myclobutanil</td>
<td>+++</td>
<td>-</td>
<td>+++</td>
<td>-</td>
</tr>
<tr>
<td>Elevate 50WDG</td>
<td>Fenhexamid</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Vangard 75WG</td>
<td>Cyprodinil</td>
<td>+++</td>
<td>+++</td>
<td>-</td>
<td>?</td>
</tr>
<tr>
<td>Scala 600SC</td>
<td>Pyrimethanil</td>
<td>+++</td>
<td>+++</td>
<td>-</td>
<td>?</td>
</tr>
<tr>
<td>Abound 4F</td>
<td>Azoxystrobin</td>
<td>++</td>
<td>-</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Flint 50WDG</td>
<td>Trifloxystrobin</td>
<td>++</td>
<td>-</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Pristine 38WG</td>
<td>Pyraclostrobin boscalid</td>
<td>++++</td>
<td>+++</td>
<td>+++</td>
<td>?</td>
</tr>
<tr>
<td>Quintec 2L</td>
<td>Quinoxyfen</td>
<td>-</td>
<td>-</td>
<td>+++</td>
<td>-</td>
</tr>
</tbody>
</table>

* - Data shown from ‘www.ipm.ucdavis.edu’.
Summary of management of brown rot with preharvest fungicide treatments

• Numerous highly effective treatments are available
• Current trend in fungicide registrations are pre-mixture products
  – Highly effective
  – Consistent
  – Built-in resistance management
• Pre-harvest treatments
  – 14 or 7 PHI very effective but rate dependent; 14 and 7 PHI more consistent with lower labeled rates
  – Fungicide characteristics are important in their performance
    – AP fungicides appear to be heat/humidity unstable with rapid decline of residues, DMIs have some locally systemic activity – persistent if rainfall
  – Biologicals/natural products sometimes effective (inconsistent)
## Treatment timing for peach diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Dormant</th>
<th>Delayed Dormant</th>
<th>Bloom Early (5-20%)</th>
<th>Bloom Late (40-80%)</th>
<th>3-6 weeks postbloom</th>
<th>Preharvest a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown rot</td>
<td>----</td>
<td>----</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td>----/ND</td>
<td>----</td>
<td>++</td>
<td>+++</td>
<td>+++^e</td>
<td>----</td>
</tr>
<tr>
<td>Leaf curl b</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Rust c</td>
<td>+</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Scab d</td>
<td>----</td>
<td>----</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>----</td>
</tr>
<tr>
<td>Shot hole d</td>
<td>+++</td>
<td>----</td>
<td>+</td>
<td>+++</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

a - Rating: +++ = most, ++ = moderately, + = least effective, and ND = no data.

b - Treatment should be made before bud break and preferably before bud swell.

### Additional Table

<table>
<thead>
<tr>
<th>Disease</th>
<th>Dormant</th>
<th>Bloom 20-40%</th>
<th>Bloom 80-100%</th>
<th>3-6 weeks postbloom</th>
<th>Preharvest 3 weeks</th>
<th>Preharvest 1 week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown rot</td>
<td>----</td>
<td>1, 2 (+oil)</td>
<td>1, 2 (+oil)</td>
<td>3, 3/11</td>
<td>3, 3/11</td>
<td>3, 3/11</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td>----/M2</td>
<td>1, 2+oil, 3</td>
<td>1, 3, 7/11</td>
<td>3, 7/11, 11, M2, NP/BC</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

www.ipm.ucdavis.edu
EFFICACY AND TIMING OF FUNGICIDES, BACTERICIDES, AND BIOLOGICALS FOR DECIDUOUS TREE FRUIT, NUT CROPS, AND GRAPEVINES 2013

ALMOND  PEACH
APPLE AND PEAR  PISTACHIO
APRICOT  PLUM
CHERRY  PRUNE
GRAPE  WALNUT

Jim Adaskaveg, Professor
University of California, Riverside

Doug Gubler, Extension Plant Pathologist
University of California Davis

Themis Michailides, Professor
University of California, Davis/Kearney Agricultural Center

Web Site Addresses
UC Davis, Dept. of Plant Pathology
www.plpnem.ucdavis.edu

www.ipm.ucdavis.edu
Summary of management of brown rot by crop

- **Apricot, prune, and sweet cherry**
  - Highly susceptible to blossom blight and fruit rot (fruit clusters)
  - All flower parts are susceptible – Start early (1-3 sprays)
  - Fruit – Cover sprays starting after shuck split and then preharvest (3 weeks before harvest)

- **Peaches and nectarines**
  - Moderately susceptible to blossom blight and highly susceptible to fruit rot
  - Pistal and stamen infections lead to blossom blight (1-2 sprays)
  - Fruit – Cover sprays starting after shuck split and then preharvest (3 weeks before harvest)

- **Plums**
  - Less susceptible to blossom blight (0-1 spray)
  - Blossom sprays are needed when large number of mummies present
  - Cover sprays starting after shuck split and then preharvest (3 weeks before harvest)
Components of postharvest decay management

Preharvest practices
Harvest practices
Postharvest practices
Crop handling
Sanitation
Biocontrols
Fungicides
Physical modification of the environment
Growth regulators
Strategies for integrated management of postharvest decays

Crop handling – reduce crop injuries, minimize process time
Temperature management -
   * **Cold** - slow physiological processes of pathogen and host
   * **Hot** – eradicate the pathogen
Atmosphere management – MA, CA
Sanitation – (oxidizers)
   - reduce pathogen levels in wash water
   - prevent inoculation
Biological controls – competition, antibiosis, site exclusion
Chemical control – fungicides to inhibit fungal growth
### Advantages and dis-advantages of management methods of postharvest decays

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Handling</td>
<td>Minimizes injuries</td>
<td>Pre- and postharvest infection</td>
</tr>
<tr>
<td>Temperature</td>
<td>Slows development</td>
<td>Does not eradicate</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Slows development</td>
<td>Does not eradicate</td>
</tr>
<tr>
<td>Sanitation</td>
<td>Water Disinfestation</td>
<td>Does not disinfect wounds</td>
</tr>
<tr>
<td>Biological control</td>
<td>Protectant</td>
<td>Inconsistent</td>
</tr>
<tr>
<td>Chemical</td>
<td>Systemic &amp; Protective - Consistent</td>
<td>Residues (MRL)</td>
</tr>
</tbody>
</table>
Postharvest decay management

- Infections occurring before harvest
- Quiescent infections
- Infections occurring during and after harvest (injuries!)
- Active fruit decay in the orchard
- Postharvest fruit decay in storage and during transport and marketing
- Target of postharvest fungicide treatments
Newer postharvest fungicides for temperate and sub-tropical crops – 5 FRAC groups

- **DMI - 3**
  - Tebuconazole (Elite, Tebuzol)
  - 1997

- **Phenylpyrrole - 12**
  - Fludioxonil (Scholar, Graduate)
  - 1997

- **Hydroxyanilide - 17**
  - Fenthiamid (Judge)
  - 2003

- **Anilinopyrimidine - 9**
  - Pyrimethanil (Penbotec)
  - 2005

- **QoI - 11**
  - Azoxystrobin
  - 2008

- **DMI - 3**
  - Difenoconazole
  - 2006

- **DMI - 3**
  - Propiconazole (Mentor)
  - 2014-pending

*DMI = Demethylation inhibitor (SBI), QoI = quinone outside inhibitor*
Postharvest fungicide pre-mixtures

- **DMI** Imazalil + Phenylpyrrole Fludioxonil = Philabuster citrus - registered
- Phenylpyrrole Fludioxonil + QoI Azoxystrobin = Graduate A+ Citrus - registered
  - Fludioxonil + Azoxystrobin + DMI Propiconazole = Citrus – in development
- Phenylpyrrole Fludioxonil + MBC TBZ = Scholar Max MP Pome fruit - registered
  - Phenylpyrrole Fludioxonil + DMI Difenoconazole = Pome fruit - in development
  - Phenylpyrrole Fludioxonil + DMI Propiconazole = Stone fruit - in development

*and others ....*
### Toxicity data for new 'reduced-risk' postharvest fungicides and “permitted” preservatives

<table>
<thead>
<tr>
<th>Fungicide /Preservative</th>
<th>Class</th>
<th>LD$_{50}$ rat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fludioxonil</td>
<td>Phenylpyrrole</td>
<td>&gt;5,050 mg/kg</td>
</tr>
<tr>
<td>Azoxylostrobine</td>
<td>QoI</td>
<td>&gt;5,000 mg/kg</td>
</tr>
<tr>
<td>Fenhexamid</td>
<td>Hydroxyanilide</td>
<td>&gt;2,000 mg/kg</td>
</tr>
<tr>
<td>Pyrimethanol</td>
<td>Anilinopyrimidine</td>
<td>&gt;5,000 mg/kg</td>
</tr>
<tr>
<td>Benzoic acid</td>
<td>Organic acid</td>
<td>1700 mg/kg</td>
</tr>
<tr>
<td>Sorbic acid</td>
<td>Organic acid</td>
<td>&gt;4000 mg/kg</td>
</tr>
<tr>
<td>Natamycin</td>
<td>Macrolide polyene</td>
<td>&gt;5000 mg/kg</td>
</tr>
</tbody>
</table>
Multiple active ingredients are/will be registered on many fruit crops in the US

- The group of new-generation postharvest fungicides has an overlapping spectrum of activity and several compounds are/will be registered for most crops.
  - Increased spectrum of activity
  - Different markets have different MRLs (export limitations)
  - Application of mixtures of different classes to reduce pressure for resistance selection: Resistance management and fungicide stewardship
# Efficacy of Fungicides against Postharvest Decays

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>FRAC Group</th>
<th>Brown rot</th>
<th>Gray mold</th>
<th>Rhizopus rot</th>
<th>Sour rot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tebuconazole (cherry and plum)</td>
<td>3</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Propiconazole</td>
<td>3</td>
<td>++++</td>
<td>+/-</td>
<td>++</td>
<td>++++</td>
</tr>
<tr>
<td>Penbotec</td>
<td>9</td>
<td>+++</td>
<td>+++</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Fludioxonil</td>
<td>12</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>+</td>
</tr>
<tr>
<td>Fenhexamid</td>
<td>17</td>
<td>+++</td>
<td>++++</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Iprodione with oil</td>
<td>2</td>
<td>++++</td>
<td>++++</td>
<td>+++</td>
<td>---</td>
</tr>
</tbody>
</table>

Rating: ++++ = excellent; ++ = very good; + = some activity; - not active.

[Reduced risk symbol]
Common application methods for postharvest fungicides

- Drenches
- High volume sprayers
- Low volume sprayers (CDA)
Evaluation of new and registered postharvest treatments for postharvest decay management

Experimental conditions that closely mimic commercial conditions
• Experimental packingline studies
• Use of commercial application systems
• Use of fruit coatings
• Evaluation of pre-infection activity simulating conditions when fruit are infected after fungicide treatment
• Evaluation of post-infection activity simulating when fruit is treated up to 20 h after initiation of infection (e.g., harvest)
## Evaluation of new and registered postharvest treatments for postharvest decay management of sweet cherry

### Incidence of decay

<table>
<thead>
<tr>
<th>Inoculated-Treated</th>
<th>M. fructicola</th>
<th>B. cinerea</th>
<th>R. stolonifer</th>
<th>G. candidum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Scholar 230SC 16 fl oz</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>Scholar 16 fl oz + Mentor 4 oz</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>Mentor 45WP 4 oz</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>Tebuzol 45DF 8 oz</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>Tebuzol 45DF 16 oz</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>b</td>
</tr>
</tbody>
</table>

**Note:** Values with different letters (a, b, c) are significantly different at the 0.05 level.

- Brown rot is effectively controlled by all three fungicides.
- Scholar-Mentor mixtures and Tebuzol at high rates is highly effective against all four decays.
Low-volume spray vs. in-line drench applications of Scholar to Spring Flame peaches in an experimental packingline study

Fruit inoculated, treated after 10-15 h

Aqueous in-line drenches over a roller bed followed by CDA wax or CDA application in wax.

Lower rates of Scholar can be used in in-line drench applications with equal efficacy to CDA applications.
Low-volume spray vs. in-line drench applications of Scholar to Casselman Plums in an experimental packingline study

Fruit inoculated, treated after 14-16 h

Aqueous in-line drenches over a roller bed followed by CDA wax or CDA application in wax (10 gal/200k lb).

Lower rates of Scholar can be used in in-line drench applications with greater efficacy than CDA applications.
Postharvest brown rot management

- Several highly effective fungicides are registered in the United States on specific crops: Fludioxonil, pyrimethanil, propiconazole, tebuconazole, fenhexamid.
  - Broad spectrum
  - Low rates
  - High food safety

- Different modes of action minimize the selection of resistance if treatments are properly applied.

- Treatments are effective as protectants and sometimes as eradicants (post-infection activity up to 24 h)

- MRLs established for some of these fungicides worldwide.
**Fungicide resistance**

- **Definitions**

- **Resistance** is the reduction in sensitivity beyond natural variation.

- Natural variation is described as the **baseline sensitivity**. Baseline sensitivities are based on a sample of pathogen individuals that were never exposed to the fungicide.
  - Baseline sensitivities have been established for the most important pathogen-fungicide systems.

- **Field-resistance (practical resistance)** is the reduction in sensitivity in the pathogen that is accompanied by crop losses.
Anti-resistance strategies
Resistance management is a game of numbers and survivorship

- “Minimize pathogen survivors” - Do not compromise control by minimizing rates or coverage
- Rotation between different classes and MOAs
- Limit the number of applications of any MOA (Enough different classes of materials are or will be registered to limit each MOA to one/season)
Anti-resistance strategies for fungicides

- Fungicides within the same chemical class have the same mode of action. Thus, knowledge on the class of a particular fungicide being used is important.

*Unlike insecticide-resistance, with fungicides cross-resistance patterns generally follow modes-of-action, presumably reflecting target site alterations rather than uptake and detoxification changes.*

*Kendall and Hollomon, 1998*
Anti-Resistance Strategies for Postharvest Fungicides

- Post-Registration Strategies -

- Follow the RULES of Fungicides Stewardship -

- Rotate between different classes of fungicides or use pre-mixtures prior to the development of resistance.
- Use labeled rates and optimize application.
- Limit total number of fungicide applications of any one class to 1 per fruit lot.
- Educate yourself about fungicide activity, mode of action, and class.
- Start a fungicide management program with the use of sanitizers to reduce the amount of inoculum on fruit and equipment.
Questions!
Additional information
Alternate-row spraying for control of blossom diseases

- A method that is being increasingly used in California orchards for control of blossom diseases
- Savings in cost for labor and fungicides

Methods: Trees were sprayed with Vangard (cyprodinil) or Laredo (myclobutanil) from only one side. Blossoms were collected from the sprayer-facing and the opposite sides of the tree for inoculation and fungicide residue analysis.
Spray coverage on near, middle, and far sides of tree

Spray cards that were attached to the tree at application time were used as indicators of fungicide coverage.
Disease evaluations of Laredo-treated blossoms after inoculation with *M. laxa* 2002

**Butte – Treated at 80% Bloom**

<table>
<thead>
<tr>
<th>Anther infection (%)/Residue</th>
<th>Control</th>
<th>Near side</th>
<th>Far side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>98.5%/ND</td>
<td>10.8%/10.3 ppm</td>
<td>57%/3.1 ppm</td>
</tr>
</tbody>
</table>

Detached blossoms were spray-inoculated with conidia of *M. laxa*.
Conclusions of studies on alternate-row spray programs

Alternate row spraying reduces fungicide efficacy and fungicide residues on the ‘far-side’ of the trees.

Exposure of the pathogen to lower fungicide concentrations may favor the selection of resistant pathogens by increasing population size.

Alternate-row application programs may reduce disease management costs, but may be a high-risk practice that potentially leads to fungicide resistance in the field.

If alternate-row spraying is done, it should only be conducted at the pink bud stage of bloom (5%) of susceptible varieties to allow adequate fungicide coverage.
How does resistance develop?
- The pathogen component of resistance development -

The inherent resistance frequency in a population depends on the type of pathogen and on the type of fungicide. It can range from ca. 1 individual/10\(^4\) individuals to 1 individual/10\(^6\) individuals.
Resistance development in pathogen populations

Recipe for resistance development

**Lab**
- Large amount of pathogen propagules
- Low fungicide concentration
- Repeated exposure to the fungicide
  
  = Resistance development is optimal

**Field**
- Conducive environment, susceptible varieties, improper timing
- Alternate row, Air application, Off-Label use
- Repeated usage of fungicide class
  
  = Resistance development is optimal