Postharvest Disease Management

- Principles and Treatments -

James E. Adaskaveg

Professor

Department of Plant Pathology

University of California, Riverside
Postharvest decay organisms

Fungi (eukaryotic organisms):
• Most important
• Mostly members of the Ascomycetes and Fungi imperfecti
• Propagation and dissemination by abundantly produced, mostly asexual spores
• Infection through wounds or sometimes through intact fruit surface.

Bacteria (prokaryotic organisms):
• Mostly pathogens of vegetables
• *Erwinia carotovora* is the most important postharvest pathogen causing a soft rot.
• Infections only through wounds.
Major postharvest decays of pome fruits

Gray mold decay of Bosc and Asian pear caused by *Botrytis cinerea*

Penicillium decay of Bosc pear caused by *Penicillium expansum*

Alternaria decay of Asian pear caused by *Alternaria* sp.

Anthracnose of apple caused by *Colletotrichum acutatum*
Postharvest decays of stone fruits

Brown rot (*Monilinia fructicola*)
Gray mold (*Botrytis cinerea*)
Rhizopus rot (*Rhizopus stolonifer*)
Sour rot (*Geotrichum candidum*)

Infection through wounds and of senescent tissues

Infection through wounds of ripe fruit

Infection through wounds and of healthy tissues
Postharvest decays of citrus

Green mold caused by *Penicillium digitatum* (most important on citrus)

Blue mold caused by *P. italicum* and green mold

Brown rot caused by *Phytophthora* spp. Infection through intact tissue.

*Penicillium* spp. are wound pathogens

Penicillium soilage
Major postharvest decays of citrus

Sour rot caused by *Geotrichum citri-aaurantii*

Alternaria decay caused by *Alternaria* sp.

Tear stain and anthracnose caused by *Colletotrichum gloeosporioides*

Stem end rot caused by *Lasiodiplodia theobromae* (B. rhodina)
Postharvest decays of pomegranates and kiwifruit

Gray mold caused by *Botrytis cinerea*

Infection through flower parts

Infection through cut stem ends at harvest
Major postharvest decays of strawberry

Gray mold decay caused by *Botrytis cinerea*

Anthracnose caused by *Colletotrichum acutatum*
Penetration through wounds – Wound pathogens:

- Most common
- Only minor wounds required (micro-wounds).
- Wounds commonly occur before harvest (insect injuries, wind damage, etc.) or more frequently during and after harvest during handling, transport, packaging.
- **Goal in postharvest handling:** Minimize fruit injuries.

Penetration of intact fruit:

- Through surface of mature fruit.
- Quiescent infections that are established early during fruit growth but remain inactive until the fruit matures.
- Colonization of flower parts, invasion of maturing fruit
Infection by postharvest decay fungi

Conidiophore and conidia (asexual spores) of *Botrytis cinerea*

Spore germination: requires water, oxygen, and sometimes nutrients

Host infection:
Penetration (through wounds or directly), inter- and intracellular growth. Enzymatic activities dissolve host cell walls and contents. Sometimes production of toxins that kill host cells.
The Disease Triangle of Plant Pathology -
- A re-occurring interaction of host, pathogen and environment -

- Physiology, optimum harvest date
- Identification, biology, ecology
- Conducive parameters during storage, transportation, marketing
Principles of Plant Disease Management

- Preventative (population)
  - Avoidance of the pathogen (Cultural practices)
  - Host resistance (Resistant varieties)
  - Exclusion (Quarantines and *Sorting/Grading*)
  - Eradication (Eliminating or reducing inoculum - *Sanitation*)
  - Protection/Prevention (Chemical or biological or physical treatments – *Cold temperature*)

- Curative (individual)
  - Therapy (Physical or chemical treatments)

* - Main postharvest practices for susceptible crop.
Sanitation washes using oxidizing materials (chlorine, ozone, peroxide, etc.)

Preventative Practices - Eradication

No

Micro-organisms in stem punctures, pits, injuries, natural cracks, or bruises, residual activity

Yes

Disinfestation of non-injured commodity surfaces and of micro-organisms in water
## Comparison between postharvest sanitation and fungicide treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Delivery System</th>
<th>Sources</th>
<th>Activity</th>
<th>Advantages</th>
<th>Dis-advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>Water</td>
<td>Gas or liquid</td>
<td>Fruit surface/In solution</td>
<td>Inexpensive, effective at low rates</td>
<td>Sensitive to pH and organic load; corrosive; reactive</td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>Water</td>
<td>On-site generation</td>
<td>Fruit surface/In solution</td>
<td>Less sensitive to organic load</td>
<td>Initial cost of equipment; corrosive; training</td>
</tr>
<tr>
<td>Ozone</td>
<td>Water (low solubility)/Air</td>
<td>On-site generation</td>
<td>In solution, but poor solubility; Air: anti-sporulation</td>
<td>Non-chlorine based, no disposal issues</td>
<td>Poor water solubility, initial cost of equipment; corrosive; training</td>
</tr>
<tr>
<td>Acidified hydrogen peroxide</td>
<td>Water</td>
<td>Liquid</td>
<td>Fruit surface/In solution; some wound activity</td>
<td>Less sensitive to organic load and pH, no disposal issues</td>
<td>Conc. limits, cost, some sensitivity to Cl, pH, and organic load</td>
</tr>
<tr>
<td>Postharvest fungicide (e.g., Scholar)</td>
<td>Water</td>
<td>Dry or liquid Formulation</td>
<td>Wound protection</td>
<td>Highly effective</td>
<td>Residues; safety concerns; export tolerances (MRLs)</td>
</tr>
</tbody>
</table>
Chlorination in a hydrocooler (re-circulating)

Chlorination on a brush bed (non-re-circulating)

Critical factors

- Concentration
- Contact time
- pH
- Organic load
- Temperature

- Concentration
- Contact time
- pH
Strategies of postharvest decay control for protection, suppression, or eradication of decay

Altering the micro-environment

- Treatments with indirect effects on pathogen:
  - Change in pH
- Treatments with direct effects on pathogen:
  - Biocontrols: Competition, antibiosis, parasitism
  - Fungicides: Direct toxicity

Altering the host physiology and susceptibility

- Indirect effect on pathogen
- Plant growth regulators (PGRs)
  - Gibberellin (citrus)
  - 2,4-D (citrus)
  - Ethylene biosynthesis inhibitors?
- Effective against weak pathogens
**Altering the micro-environment**

*Treatments with indirect effects on the pathogen:*
- Change in pH
- Alkaline solutions of borax, sodium carbonate (soda ash), and sodium bicarbonate
- Accumulation of acid in potential infection sites, (e.g. SO₂)

*Treatments with direct effects on pathogen:*

**Biocontrols:** Competition, antibiosis, parasitism

**Fungicides:** Direct toxicity
Borax, sodium carbonate (soda ash), and sodium bicarbonate

- **Change in pH**
  - Accumulation of alkali in potential infection sites on fruit surface

- **Germination of pathogen spores is inhibited (fungistatic action)**
  - Heated solutions are more toxic

- **Disadvantages**
  - Change in pH is gradually reversed by acid fruit juice
  - Fruit staining
  - Fruit dehydration
  - No residual activity
Usage of borax, sodium carbonate (soda ash), and sodium bicarbonate in postharvest treatments of lemons.
Usage of borax, sodium carbonate (soda ash), and sodium bicarbonate in postharvest treatments of lemons.

Treatment with heated soda ash

Water rinse after soda ash treatment
Altering the micro-environment

*Treatments with indirect effects on the pathogen:*
- Change in pH
- Alkaline solutions of borax, sodium carbonate, and sodium bicarbonate

*Treatments with direct effects on pathogen:*
- **Biocontrols:** Competition, antibiosis, parasitism
- **Fungicides:** Direct toxicity
Biocontrols: Competition, antibiosis, parasitism

- Development is driven by safety concerns
- Activity from laboratory experiments is difficult to transfer into a commercial scale
- No activity against existing infections (infections that occur at harvest)
- Efficacy is generally inconsistent and never complete
- Previously, 2 products registered:
  - Aspire (*Candida oleophila*), no longer manufactured
  - Bio-Save (*Pseudomonas syringae*), still in use
Bio-Save 10 LP

**ACTIVE INGREDIENT:**

*Pseudomonas syringae* Strain ESC-10 ........................................ 29.8%

**INERT INGREDIENTS:** .......................................................... 70.2%

Total .......................................................... 100.0%

Note: Contains a minimum of $9 \times 10^{10}$ colony forming units per gram of formulated product.

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The biocontrol Bio-Save is registered for postharvest use.
<table>
<thead>
<tr>
<th>Biocontrol</th>
<th>Organism</th>
<th>Crops</th>
<th>Decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td><em>Pseudomonas syringae</em></td>
<td>Apples, pears, citrus</td>
<td>Penicillium Decays</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sweet cherry</td>
<td>Gray mold, Penicillium decays</td>
</tr>
<tr>
<td>Yeast</td>
<td><em>Candida oleophila</em></td>
<td>Pome fruit</td>
<td>Penicillium Decays</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Citrus</td>
<td>Penicillium Decays</td>
</tr>
</tbody>
</table>
Biocontrol products registered in other countries

- **YieldPlus** (*Cryptococcus albidus*) – developed in South Africa for pome fruit
- **Avogreen** (*Bacillus subtilis*) – South Africa for avocado
- **Shemer** (*Metschnikowia fructicola*) – Israel for apricot, peach, citrus, grapes, pepper, strawberry, sweet potato

- Several other products based on *Candida sake*, *Candida oleophila*, and *Aureobasidium pullulans*, are in development.
### Postharvest treatments approved for organic produce and their limitations

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium bicarbonate</td>
<td>Short-lived</td>
</tr>
<tr>
<td>Calcium chloride and other chlorine products</td>
<td>Only water and surface-disinfestation</td>
</tr>
<tr>
<td>(with their rates defined by OMRI)</td>
<td></td>
</tr>
<tr>
<td>Diluted ethanol (not in the US)</td>
<td>Highly regulated by government</td>
</tr>
<tr>
<td>Heat</td>
<td>Cost, damaging to some crops</td>
</tr>
<tr>
<td>UV irradiation</td>
<td>Cost, damaging to some crops</td>
</tr>
<tr>
<td>Biocontrol agents</td>
<td>Inconsistent</td>
</tr>
</tbody>
</table>
## Prevention, suppression, and eradiction of postharvest decays

**Fungicides vs. biological controls**

<table>
<thead>
<tr>
<th>Fungicides</th>
<th>Biological controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single synthetic active ingredient</td>
<td>Mixtures of active and inactive ingredients. Active ingredient often unknown.</td>
</tr>
<tr>
<td>Well characterized chemically and toxicologically</td>
<td>Chemically and toxicologically often poorly characterized, but considered natural.</td>
</tr>
<tr>
<td>Efficacy generally high</td>
<td>Efficacy variable</td>
</tr>
</tbody>
</table>
Development of Fungicides for Management of Plant Diseases

Initially, developed as simple elements or organic compounds that are non-systemic in plant tissue, and have a low-resistance potential to target organisms......

but over time, they have been developed as more complex organic compounds, that may be systemic in plant tissue, and have a high-resistance potential to target organisms.
Fungicides have a specific spectrum of activity and, in most cases, are suitable for a limited number of crops
Classes of postharvest fungicides

- Compounds within each fungicide class have:
  - Similar chemical structures
  - A similar mode of action that targets either a single site or multiple sites in the biochemical pathways of the fungus
- Cross-resistance may occur among compounds within the same chemical class
Important older postharvest fungicides for citrus and pome fruits that are still being used today

<table>
<thead>
<tr>
<th>Residual Fungicide</th>
<th>Class/Grouping</th>
<th>Crops</th>
<th>Decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOPP</td>
<td>Phenol</td>
<td>Citrus</td>
<td>Penicillium decay, sour rot</td>
</tr>
<tr>
<td>Thiabendazole</td>
<td>Benzimidazole</td>
<td>Citrus, pome fruit</td>
<td>Penicillium decay, gray mold</td>
</tr>
<tr>
<td>Imazalil</td>
<td>SBI-Imidazole</td>
<td>Citrus</td>
<td>Penicillium Decays</td>
</tr>
</tbody>
</table>
Towards safer postharvest decay control materials

Re-registration requirements of older pesticides

**Reduced Risk Pesticides** (an EPA Classification)
- A relative term that is applied to a pesticide as compared to currently registered pesticides of a crop group.
- A pesticide that broadens the adoption of IPM practices or reduces:
  - Exposure risk to humans
  - Potential toxicity to non-target organisms
  - Contamination of the environment

Primarily reduced-risk fungicides will be registered for postharvest use in the US
Benefits of postharvest reduced-risk fungicides to prevent decay

Untreated and postharvest treated (Scholar) peaches and sweet cherries
<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Class</th>
<th>Crops</th>
<th>Decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tebuconazole</td>
<td>SBI-Triazole</td>
<td>Sweet cherry</td>
<td>Brown rot, Rhizopus, and Mucor decays</td>
</tr>
<tr>
<td>Fludioxonil</td>
<td>Phenylpyrrole</td>
<td>Stone fruit, pome fruit, pomegranate, kiwifruit, citrus, tuber crops</td>
<td>Brown rot, gray mold, Rhizopus Rot, Penicillium decays</td>
</tr>
<tr>
<td>Azoxystrobin</td>
<td>Qol</td>
<td>Citrus potato</td>
<td>Penicillium decays</td>
</tr>
<tr>
<td>Fenhexamid</td>
<td>Hydroxyanilide</td>
<td>Stone fruit, pome fruit, pomegranate, kiwifruit</td>
<td>Brown rot, gray mold</td>
</tr>
<tr>
<td>Pyrimethanil</td>
<td>Anilinopyrimidine</td>
<td>Stone fruit, pome fruit, citrus</td>
<td>Penicillium decays, brown rot, gray mold</td>
</tr>
<tr>
<td>Difenoconazole</td>
<td>SBI-Triazole</td>
<td>Pome fruit, tuber crops</td>
<td>Penicillium decays, Bull’s eye rot, Rhizopus rot</td>
</tr>
<tr>
<td>Propiconazole</td>
<td>SBI-Triazole</td>
<td>Stone fruit, citrus, tomato</td>
<td>Penicillium decays, brown rot, gray mold, sour rot</td>
</tr>
</tbody>
</table>

**Fungicide is already registered**

*new registrations or proposals are in bold italics*
Application of postharvest fungicide treatments

- Drenches
- High volume sprayers
- Low volume sprayers (CDA)

Less common:
- Dips
- Flooders
- Foamers
- Brushes
- Fumigators
- Dusters
- Paper wraps
- Box liners
Application of postharvest fungicide treatments

- High volume applications: 100-200 gal/ton of fruit
- Low volume applications: 8-30 gal/ton of fruit

Low volume application systems have become more popular because of very little run-off and no disposal problems.
Application methods for postharvest fungicide treatments

High-volume spray application ('T-Jet')
Application methods for postharvest fungicide treatments

Low-volume spray application (Controlled droplet application - CDA)
Application methods for postharvest fungicide treatments

Dip application
Application methods for postharvest fungicide treatments

Flooder application
Application methods for postharvest fungicide treatments

Flooder application
Application methods for postharvest fungicide treatments

Fogging
Application of postharvest fungicide treatments

- Aqueous applications

- Application in wax-oil emulsions
  - Not all fruit coatings are considered food-grade in different international markets
  - Prevention of water loss while still permitting gas exchange
  - Increase of shine of fruit
### Common fruit coatings used in postharvest treatments

<table>
<thead>
<tr>
<th>Type of wax</th>
<th>Prevention of water loss</th>
<th>Gas exchange</th>
<th>Shine of fruit*</th>
<th>Citrus</th>
<th>Nectar./Peach/cherry</th>
<th>Plum</th>
<th>Pome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral oil non-emulsified</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Mineral oil emulsified</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetable oils</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Carnauba</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Shellac</td>
<td>+</td>
<td>+/-</td>
<td>+++</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Wood rosin blends</td>
<td>+</td>
<td>+/-</td>
<td>+++</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Shine of fruit is not important for peaches and plums.
- Carnauba coatings are made from leaves of the Brazilian life tree. Shellac coatings are made from insect exudates. Wood rosins (ester derivatives) are extracted from pine trees.
- Mixtures of polyethylene, carnauba, shellac, and wood rosins are also used on citrus.
- Mixtures of carnauba and shellac are also used on pome fruits.
Postharvest fungicide treatments as a component of postharvest handling
Example: Lemons in California

Fruit arrival ➔ Sorting ➔ Chlorine wash, soda ash treatment, water rinse ➔ Application of fungicide and fruit coating
Storage wax application

Bulk packing in bins

Storage for up to 3 months

Pack wax application

Boxing, shipping, marketing
Chlorine wash after storage

Sorting

Boxing and marketing

Fungicide and pack wax application
Use limits of pesticides

**Residue tolerance:** Maximum residue limit or MRL of a chemical that is allowed on a specific commodity.

**Risk assessment** based on:
- Toxicological characteristics of chemical
- Amount of human consumption of a specific commodity.

*Note - Actual chemical residues are fractions of the tolerances or MRLs*
Calculations and Verification for Proper Delivery of Fungicide to Fruit

- **Fruit Weight**
  - Bin count per time
  - Fruit weight per treatment bed per time

- **Fungicide Weight per Volume**
  (Delivery rate)
  - Concentration and Flow Rate
    * Tank Mix
    * In-Line Injection

- **Sampling and residue measurements of the fungicide on the commodity** are *routinely* done and *monitored* by regulatory agencies
Stewardship of Postharvest Fungicide Treatments

Proper use to ensure food and environmental safety, as well as high-quality nutritious fruits and vegetables.

Prevention of resistance in pathogen populations to fungicides
- *Rotate* between fungicide classes
- *Use* labeled rates
- *Limit* the total number of applications
- *Education* of spectrum of activity
- *Sanitation* is essential in an integrated management program
Conclusions

Chemical treatments in postharvest decay management

- Maximum efforts have been placed on:
  - Food safety (EPA's 'Reduced-risk' fungicides)
    - No mammalian activity at registered rates
    - Lower rates (parts per million quantities)
    - Specific to target plant pathogens
  Delivery of high quality nutritious fruits and vegetables with minimal losses to growers, packers, and distributors

- Development and proper stewardship of integrated management programs cooperatively with land grant research and extension programs and federal/state regulatory agencies.
Use limits of pesticides

- **Residue tolerances** must be established for all postharvest chemical treatments except for those that are exempt:
  - EPA – exempt designation or
  - FDA – **GRAS** (Generally Regarded as Safe) designation

Examples for GRAS compounds: chlorine, potassium sorbate, potassium bisulfite, sulfur

**Residue tolerances - Maximum residue limits (MRLs)**

- Maximum residue of a chemical that is allowed to remain on the fruit – determined by EPA.
- Set below the amount that could pose a health concern.
- Different for different countries – based on consumer habits and risk analysis

**Food Additive Tolerances (FATs) – Classification as an ingredient for food use** (country specific, e.g., Japan)
Examples of maximum residue limits (MRLs) - US

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>MRL</th>
<th>LD$_{50}$ rat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fludioxonil</td>
<td>Stone fruit: 5 mg/kg</td>
<td>&gt;5000 mg/kg</td>
</tr>
<tr>
<td>Fenhexamid</td>
<td>Stone fruit: 10 mg/kg</td>
<td>&gt;2000 mg/kg</td>
</tr>
<tr>
<td>Pyrimethanil</td>
<td>Citrus: 7 mg/kg</td>
<td>&gt;5000 mg/kg</td>
</tr>
</tbody>
</table>

mg/kg = ppm

*Remember that these are maximum levels and actual residue levels are just fractions of these values to obtain desired control.*
How many apples does someone need to eat to reach the LD$_{50}$ of fludioxonil (>5000 mg/kg)?

1 ppm = 1 mg/kg
or 1 mg/10 apples

$X \, 5000 =$

50,000 apples/Kg x Body weight (70 kg for an adult) = 3.5 million apples!
Useful Publications - Books:

**Postharvest Technology of Horticultural Crops**
Edited by A. A. Kader

**Postharvest Pathology**
Edited by D. Prusky and M. L. Gullino

**Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables**
Wills et al., AVI Publishing Co., 1981

**A Colour Atlas of Post-harvest Diseases & Disorders of Fruits and Vegetables**
Useful Websites (for fungicides):

Labels and MSDS information:
http://www.cdms.net/manuf/manuf.asp
http://www.agrian.com/labelcenter/results.cfm

Maximum Residue Limit (MRL) or Tolerance information:
http://www.mrldatabase.com/
http://ec.europa.eu/sanco_pesticides/public/index.cfm

EPA Fact sheets on new active ingredients:
http://www.epa.gov/opprrd001/factsheets/
http://www.epa.gov/oppfead1/trac/safero.htm

Research:
http://californiaagriculture.ucanr.org/Landingpage.cfm?article=ca.v059n02p109&fulltext=yes
Useful Websites (Postharvest Companies):

**Service companies -**

**Decco:**
http://www.deccous.com/

**JBT (formerly FMC):**

**Pace International:**
http://www.paceint.com/

**Fungicide companies -**

**Syngenta Postharvest University:**
http://www.farmassist.com/postharvest/index.asp?nav=contact

**Janssen PMP:**
http://www.janssenpmp.com/