RECENT RESEARCH IN CALIFORNIA TO MINIMIZE POSTHARVEST DECAY OF CITRUS BY PRE- AND POSTHARVEST ACTIONS

JOSEPH L. SMILANICK
USDA ARS 9611 South Riverbend Avenue, Parlier CA
Joe.Smilanick@ars.usda.gov

Multiple-decrement concept

<table>
<thead>
<tr>
<th>Decay losses with no actions:</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action #1 20% effective</td>
<td>24%</td>
</tr>
<tr>
<td>Action #2 40% effective</td>
<td>14%</td>
</tr>
<tr>
<td>Action #3 50% effective</td>
<td>7%</td>
</tr>
<tr>
<td>Action #4 60% effective</td>
<td>3%</td>
</tr>
<tr>
<td>Final decay losses:</td>
<td>3%</td>
</tr>
</tbody>
</table>

• Postharvest decay in California and Florida compared
• What can you do before harvest?
• What can you do after harvest?
• Research in progress: Fumigation with ammonia

Multiple-decrement concept

Elements in postharvest decay management actions for citrus:

Sanitation preharvest (grove decay removal, bin cleanliness, minimize harvest to packinghouse interval)

Minimize fruit injuries (minimize drops and impacts, worker training, sorter technology, black light rooms, etc.)

Packinghouse treatments (fungicides, hot water, GRAS substances, biological control, aqueous fungicides, mixtures, temperature management)

Sanitation postharvest (reduce spore populations with chemical sanitizers, low-level constant ozone, facility design, steam or hot water cleaners.)

CA and FL decay pathogens

• California. Green/blue molds and sour rot are the major pathogens, others usually minor. Fungicide resistance a major problem, but limited to packinghouses.

• Florida. Diplodia stem end rot predominates, with green/blue molds and sour rot following. Fungicide resistance rare.

• Why? Longevity of green/blue mold conidia longer under the dry conditions of CA. Sparse CA rainfall minimizes stem end rot inoculum production and infection in groves. Degreening in CA is cooler and favors green/blue molds, while the higher FL degreening temperatures reduce these diseases. Many CA packinghouses operate year round and practice long in-house storage. No fungicides are used before harvest in CA, unlike FL.

What can you do before harvest?

Actions other than chemical control...

Very little research in recent years has been done in this area; most research directed at preharvest actions is old but still valuable...
Postharvest losses from California were up to $1,500,000 in 1904, from Florida about $500,000
USDA sent plant pathologists to California and Florida in 1905

In 1908, both groups issued long bulletins that identified rough handling as the source of most of the decay problem

“... it is now accepted without question that the elimination or reduction of the mechanical injury of the orange is one of the largest problems that the California citrus-fruit grower and packer have to overcome.” Powell, 1908

“The very foundation of decay control is careful handling; in fact, there is no substitute for it.” Winston, 1949 Florida

“It has been observed by many that this fungus can only infect citrus fruit through an injury. ...as early as 1921 [they were advised] to use the utmost care ... to avoid any possible injury to the fruit.” Christ, 1966 South Africa

Impact of careful handling on the incidence of postharvest decay on oranges after harvest

<table>
<thead>
<tr>
<th>Season</th>
<th>Hand graded</th>
<th>Typical commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1906</td>
<td>2.9</td>
<td>22.9</td>
</tr>
<tr>
<td>1907</td>
<td>2.1</td>
<td>18.2</td>
</tr>
</tbody>
</table>

Lloyd Tenny, G. W. Hosford, and H. M. White, 1908 Florida

“The excess in net return has been many times greater than the extra cost of careful handling.” Lloyd Tenny, G. W. Hosford, and H. M. White, 1908 Florida

“... In 1905, the average amount of mechanically injured fruit, based on careful inspection of more than 40,000 oranges ... was 17%.” Powell, 1908 California

“... abundant data ... show that by using care in the instruction and supervision of labor not more than 2 or 3% of oranges will be injured in handling the fruit on a commercial scale.” Powell, 1908 California

“The most common type of injury was made by ... the clippers ... many were injured by stem punctures, while others showed scratches from thorns. Other common ... injury were from gravel and twigs in the bottom of boxes and cuts by the finger nails of the pickers.” Powell, 1908 Riverside, California

G. Harold Powell
Research career 1903 - 1911

Powell, 1908 California
What can you do before harvest?

Chemical control

In repeated tests where fruit were sprayed with fungicides before harvest, Topsin (2 lbs/ac) was consistently reduced subsequent postharvest decay by 80 to 85% in repeated tests and superior to many other fungicides. Topsin is not registered in California.

At rates that controlled postharvest decay, preharvest applications of potassium phosphate, potassium sorbate, and similar organic acids or GRAS substances have injured the trees or fruit or both.

Syngenta Crop Protection, Inc. is proposing to register Quadris Top® (difenconazole FRAC group 3 + azoxystrobin FRAC group 11) for preharvest use on citrus to retard postharvest decay. Imazalil is in the same FRAC group as difenconazole, so efforts to minimize the development of resistant isolates will be particularly important.

Review and update on pre-harvest use of Topsin

Table 1: Green mold incidence on Navel oranges and its percent reduction as a result of preharvest application of different fungicides. Fruits were harvested one week after application, inoculated with P. digitatum isolate M96, dried for three days at 20°C and 3 μlylene, then stored at 0°C for one additional week.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Green mold incidence (%)</th>
<th>Reduction in green mold (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>98.9 a</td>
<td>...</td>
</tr>
<tr>
<td>Switch</td>
<td>95.8 b</td>
<td>3.1 contact</td>
</tr>
<tr>
<td>Pristine</td>
<td>92.0 c</td>
<td>7.0 contact</td>
</tr>
<tr>
<td>Headline</td>
<td>89.4 d</td>
<td>9.6 contact</td>
</tr>
<tr>
<td>Ambros</td>
<td>79.0 e</td>
<td>20.1 contact</td>
</tr>
<tr>
<td>Topsin</td>
<td>19.2 e</td>
<td>80.6 systemic</td>
</tr>
</tbody>
</table>

*Values followed by unlike letters differ significantly by Fisher’s least significant difference (*P = 0.05). An arcsin transform was applied before ANOVA, actual values are shown.

Fungicides in common use to control citrus green and blue molds of citrus

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Year</th>
<th>1970</th>
<th>1978</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiodanide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imazalil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D-Phenylphenol</td>
<td></td>
<td>1955</td>
<td></td>
</tr>
</tbody>
</table>

New citrus postharvest fungicides

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Year</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phloxine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoconostrobin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrimethan</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All are USEPA Reduced-risk
All approved 2005
**Maximum residue tolerances**

<table>
<thead>
<tr>
<th></th>
<th>Japan</th>
<th>Germany</th>
<th>USA</th>
<th>CODEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrimethanil</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Azoxystrobin</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>…</td>
</tr>
<tr>
<td>Fludioxonil</td>
<td>10</td>
<td>7</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Imazalil</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Thiabendazole</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>


**State of the art in 1925**

Wood boxes with individually wrapped fruit (for soilage control) were the industry standard

Soak tank use common - contained soda ash, sodium bicarbonate, borax-boric acid. Investigators: UC (Klotz and Fawcett) and USDA (Barger CA) (Winston FL)

**Why is the solution heated?**

- Pathogen inoculum contamination eliminated in fungicide solution
- Some decay control by heat alone
- Fungicide effectiveness increased
- Fruit cleaning improved, better wax deposition and shorter drying time
- Often fungicide residues can be reduced
- Little line space needed
- Residue on fast and uniformly w/o rotary brushing

**What can we put in the tanks?**

- Sodium bicarbonate/sodium carbonate (‘soda ash’)
  - Common food components – baking soda
  - Compatible with fungicides, improves their performance
  - Sole ‘Organic’ option, no residue issues
  - Problems: high pH, weight loss, difficult disposal in some areas, effectiveness can be poor

- Potassium sorbate
  - Very common organic acid food preservative
  - Compatible with fungicides, improves their performance
  - Exempt active ingredient EPA sec25b
  - Problems: weight loss, acceptance in Japan, effectiveness can be poor

- Potassium/calcium phosphite
  - Common fungicide for Oomycetes
  - Registration coming soon
  - Evaluation in progress, effectiveness relatively high
  - Problems: cost, weight loss

**Solutions compared**

Lemons inoculated 24 h before treatment, 1 min immersion in each solution, followed by 10 days at 20C

- Heated solutions were much more effective
Phosphoric acid
Phosphorus

Necessary for plants and all life
Fertilizer component, no fungicide properties

Valence = 5+
Accepts 5 electrons

Phosphorous acid
Phosphate

Occurs in nature but rare
Fungicide activity
Not a plant nutrient unless reduced by soil bacteria or chemically to phosphoric acid

Valence = 3+
Accepts 3 electrons

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**Soak tank solutions compared**

<table>
<thead>
<tr>
<th>Sodium bicarbonate</th>
<th>Potassium sorbate</th>
<th>Potassium phosphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness alone for green mold</td>
<td>++ to ++</td>
<td>++</td>
</tr>
<tr>
<td>When combined with imazalil + heat</td>
<td>++++</td>
<td>++++</td>
</tr>
<tr>
<td>pH (1.5% sol'n)</td>
<td>8.3 - 11.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Conductivity</td>
<td>12.2</td>
<td>8.3</td>
</tr>
<tr>
<td>Sodium</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

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**Ammonia fumigation**

**Does ammonia fumigation merit re-evaluation?**

- Simple, natural compound with known toxicology.
- Commercial sources of NH₃ are many and its price is low ($1.47 per lb)
- Previously, it was exempt from residue tolerances and may still be.
- High pH of ammonia should show synergy in interactions with modern fungicides and help manage fungicide resistant isolates.
- Insecticidal and microbial activity may be high and useful – this needs evaluation.

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**Ammonia fumigation**

Steve Tebbets USDA ARS

Clara Montesinos IVA, Valencia, Spain

- First report by Bottini (1927), then many others in 1930s; NH₃ sublimed from ammonium bicarbonate reduced Penicillium and Diplodia decay, some rind injury.
- 1950 to 1960s both in-package generators and whole room fumigation evaluated.
  - NH₃ from in-package generators worked effectively, but under commercial conditions performance was too variable and they were not implemented
  - NH₃ room fumigation was not implemented because it was unconventional and the newly introduced (at that time) fungicides controlled decay effectively and fungicide resistance was then rare.

**NH₃ rates:**

- 50-200 ppm constantly
- 500-3000 ppm in a single fumigation

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In carton NH₃ generator system

Strong base Ammonium salt

\[ \text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O} \]
Influence of ammonia fumigation on fruit quality

Ammonia fumigation to 6000 ppm did not harm Valencia oranges or Eureka lemons, but caused wounds to darken on the lemons.

The pH of the wounds several hours after treatment was increased by 0.6, 0.9, and 1.3 units, respectively, by fumigation with 1500, 3000, or 6000 ppm NH$_3$.

Synergy between imazalil and ammonia

Ammonia and imazalil interactions

pH greatly influences imazalil toxicity, and ammonia raises pH

\[ \text{Ammonia fumigated (1500 ppm)} \]

Without a doubt, ammonia fumigation accelerated natural loss of green color in lemons.

Ammonia gas fumigation

- Citrus fruit tolerate ammonia gas well and it was a promising method to control postharvest decay.
- Compressed ammonia cylinders are widely available and inexpensive (150 lbs/$220). Toxocological issues probably few.
- Initial test showed old work repeated well in a preliminary test.
- Rates of 3000 ppm (initial) for 6 hours were effective; injury potential seen at 6000 ppm on lemons. Risk of injury needs evaluation.
- Ammonia darkened and raised pH of wounds – increased pH should improve imazalil activity markedly, perhaps other fungicides as well.
- Ammonia fumigation increased rate of natural degreening of lemons – could it be done before degreening within the same rooms?
- Insecticidal and microbial activity of ammonia applied by fumigation needs evaluation.