Postharvest Disease Management

- Principles and Treatments -

James E. Adaskaveg
Professor

Department of Plant Pathology
University of California, Riverside

Postharvest decay organisms

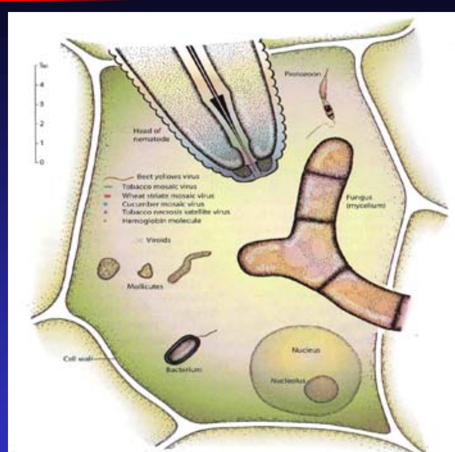


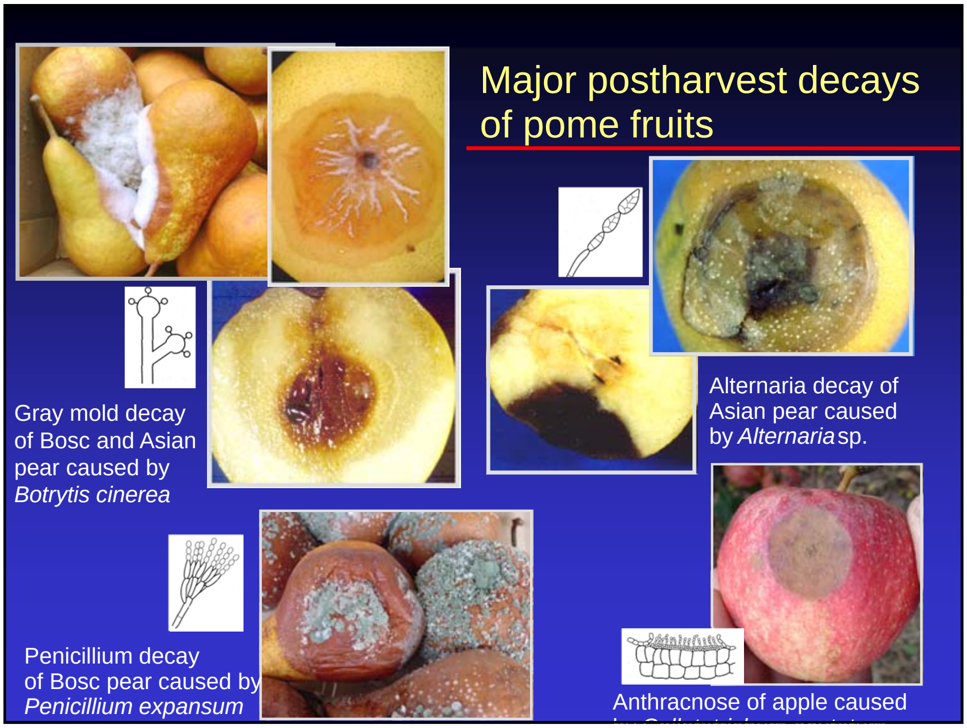
FIGURE 1-2 Schematic diagram of the shapes and sizes of certain plant pathogens in relation to a plant cell. Bacteria, mollicutes, and protozoa are not found in nucleated living plant cells.

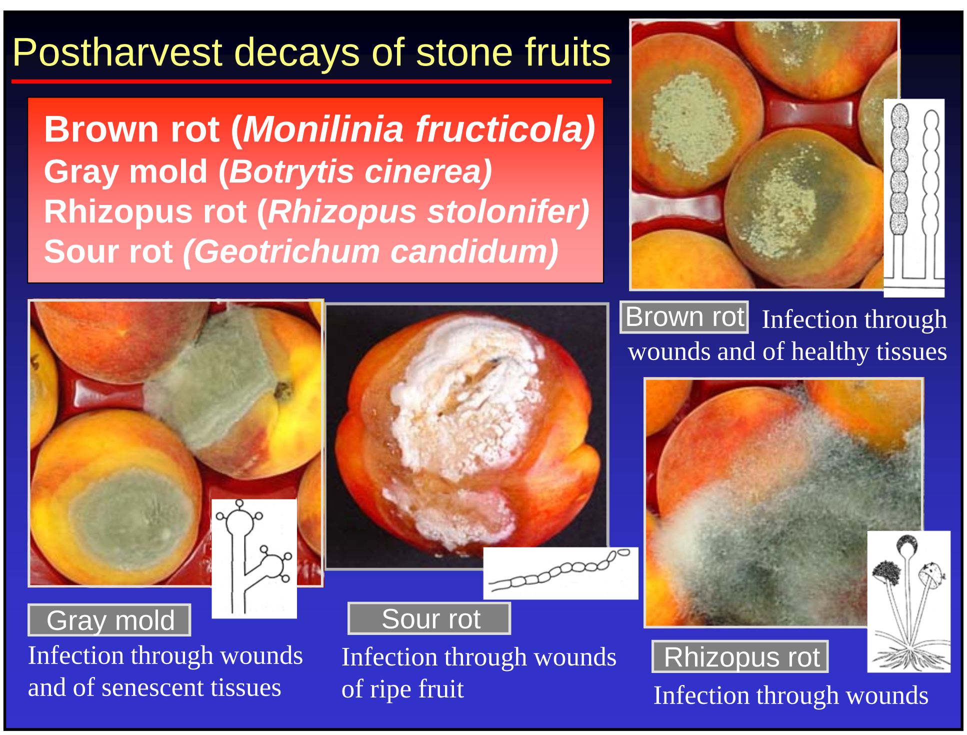
Fungi (eukaryotes):

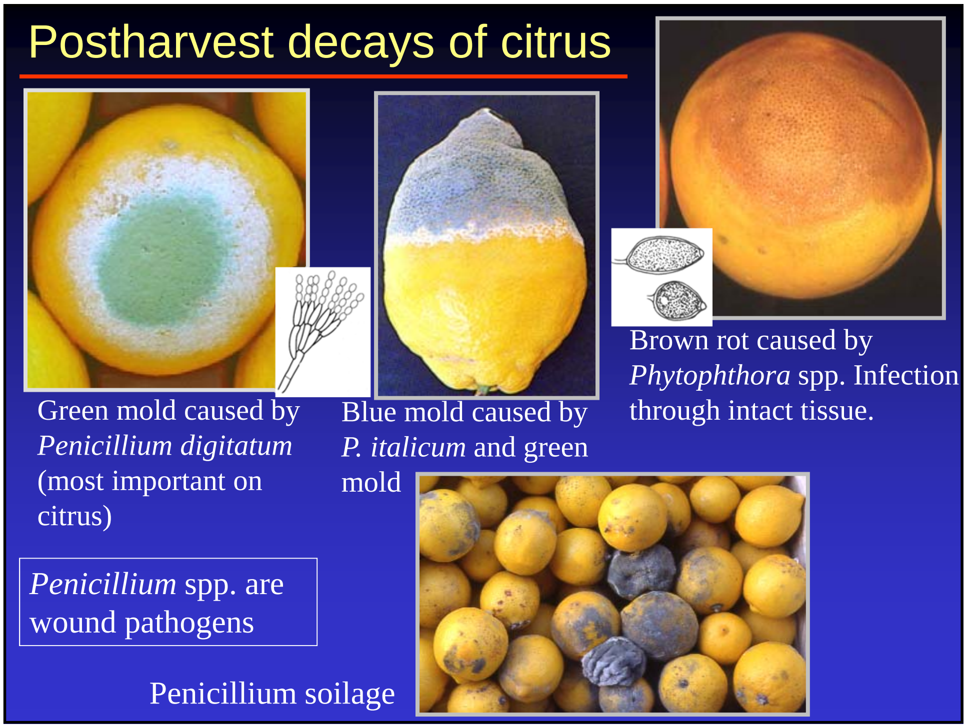
- Most important
- Reproduction and dissemination by abundantly produced spores
- Infection through wounds or sometimes through intact fruit surface.

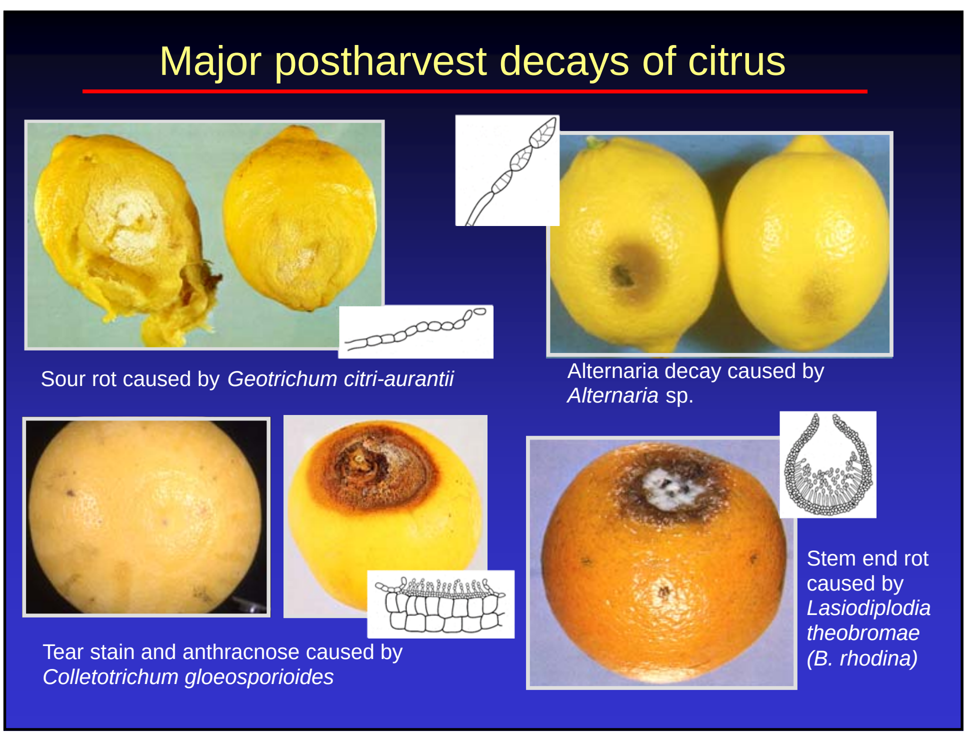
Bacteria (prokaryotes):

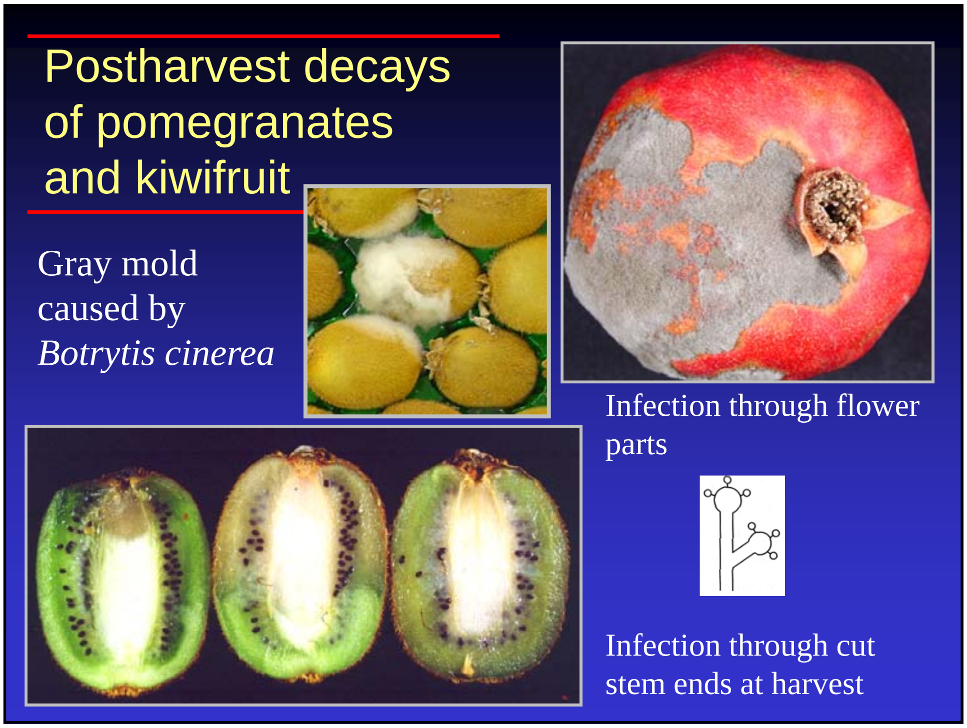
- Mostly on vegetables
- *Pectobacterium carotovora (Erwinia carotovora)* is the most important postharvest pathogen causing a soft rot.
- Infections only through wounds.

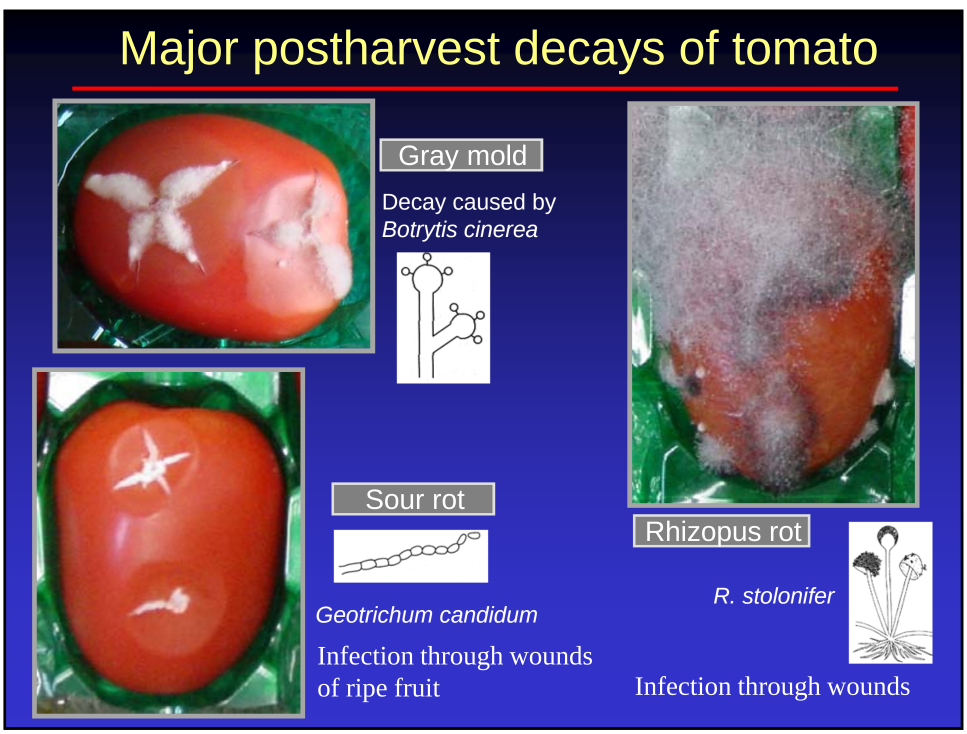

Major postharvest decays of pome fruits
Gray mold decay of Bosc and Asian pear caused by *Botrytis cinerea*
Alternaria decay of Asian pear caused by *Alternaria* sp.
Penicillium decay of Bosc pear caused by *Penicillium expansum*
Anthracnose of apple caused


Postharvest decays of stone fruits
Brown rot (*Monilinia fructicola)*
Gray mold (*Botrytis cinerea)*
Rhizopus rot (*Rhizopus stolonifer)*
Sour rot *(Geotrichum candidum)*
Brown rot
Infection through wounds and of healthy tissues
Gray mold
Infection through wounds and of senescent tissues
Sour rot
Infection through wounds of ripe fruit
Rhizopus rot
Infection through wounds


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-aurantii*
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 tomato
Gray mold
Decay caused by *Botrytis cinerea*
Sour rot
Geotrichum candidum
Infection through wounds of ripe fruit
Rhizopus rot
R. stolonifer
Infection through wounds

Postharvest decay organisms

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.**

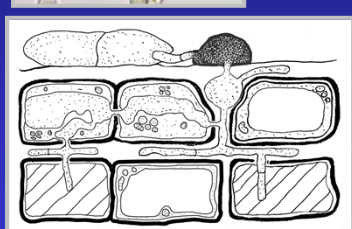
Penetration of intact fruit:

- Through intact surface of mature fruit.
- Immature fruit: Quiescent infections are established by some pathogens that remain inactive until fruit mature.
- 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

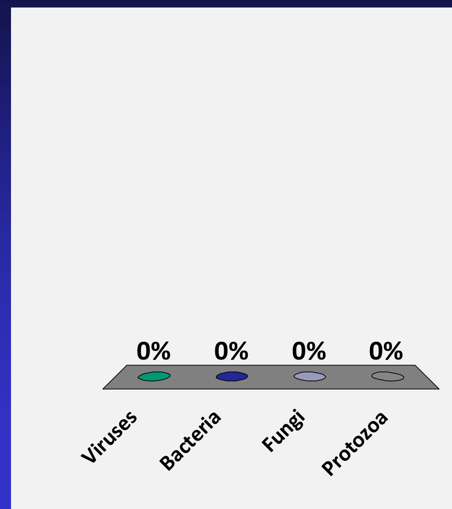


Host infection:

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.

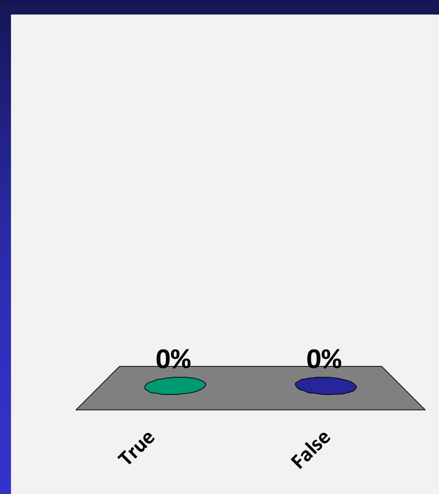
What group of micro-organisms is mostly responsible for postharvest decays?

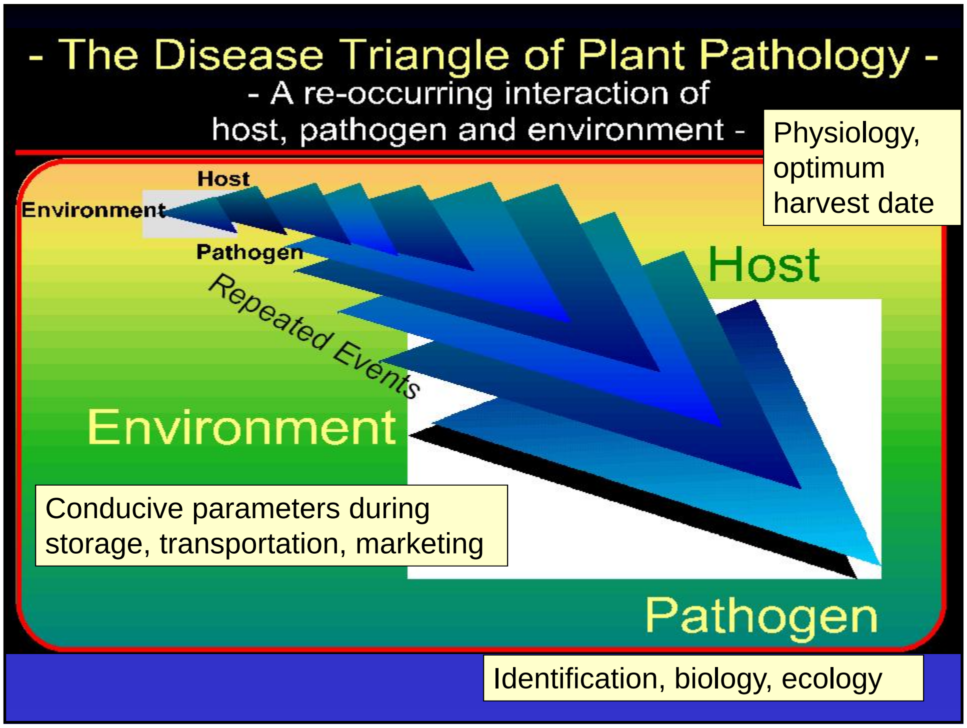
A. Viruses
B. Bacteria
C. Fungi
D. Protozoa



Fungi can only indirectly penetrate fruit.

A. True
B. False





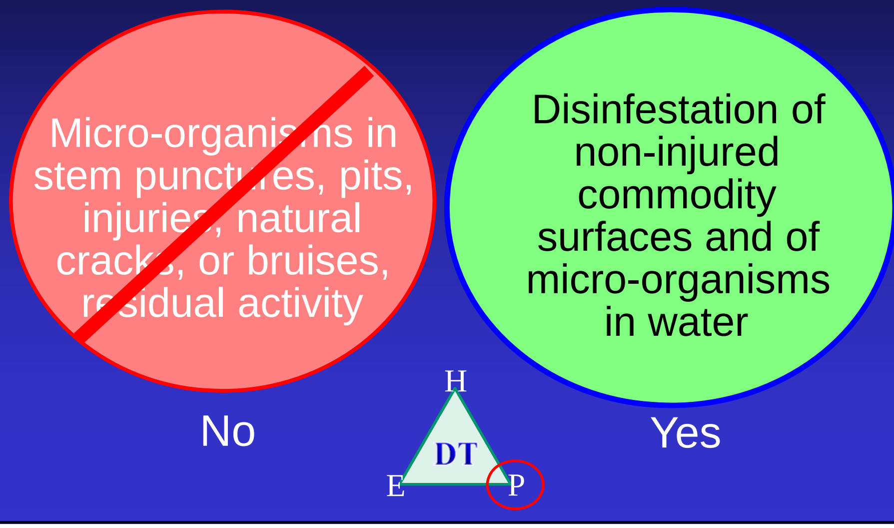
Principles of Plant Disease Management

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

* - Main postharvest practices for susceptible crop.

Preventative Practices - Eradication

Sanitation washes using oxidizing materials (chlorine, ozone, peroxide, etc.)



Effectiveness of Chlorination

- pH of Water –
  - Chlorine is most effective between 6 and 7.5.
  - Above 7.5 – less of the active form is present
  - Below 6 – noxious chloramines are present
- Organic Matter –
  - Any organic matter reduces activity
- Contact Time –
  - Longer times necessary for lower concentrations
- Temperature –
  - Less effect on activity than other parameters: Heat increases corrosiveness; cold decreases effectiveness

Comparison between postharvest sanitation and fungicide treatments

Treatment	Delivery System	Sources	Activity	Advantages	Dis-advantages
Chlorine	Water	Gas or liquid (Cl_2 or NaOCl)	Fruit surface/In solution	Inexpensive, effective at low rates	Sensitive to pH and organic load; corrosive; reactive, disposal issues
Chlorine dioxide	Water	On-site generation	Fruit surface/In solution	Less sensitive to organic load	Initial cost of equipment; corrosive; training
Ozone	Water (low solubility)/ Air	On-site generation	In solution, but poor solubility; Air: anti-sporulation	Non-chlorine based, no disposal issues	Poor water solubility, initial cost of equipment; corrosive; training
Acidified hydrogen peroxide	Water	Liquid (H_2O_2)	Fruit surface/In solution; some wound activity	Less sensitive to organic load and pH, no disposal issues	Conc. limits, cost, some sensitivity to Cl, pH, and organic load
Postharvest fungicide (e.g., Scholar)	Water	Dry or liquid formulation	Wound protection	Highly effective	Residues; safety concerns; export tolerances (MRLs)

Chlorination in a hydrocooler (re-circulating)

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

Critical factors

Hydrocooler (re-circulating):

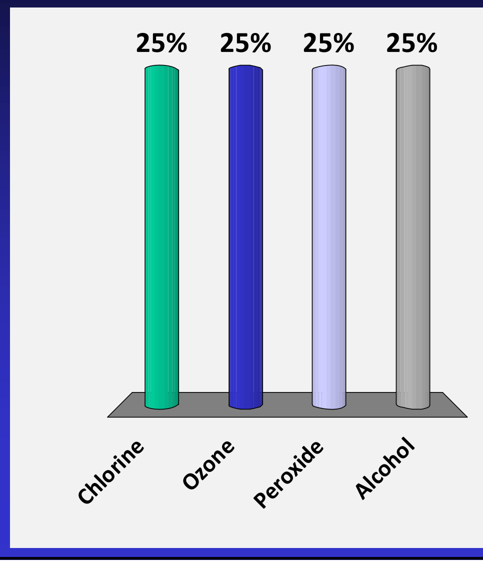
- Concentration
- Contact time
- pH
- Organic load – turbidity and COD
- Temperature

Brush bed (non-re-circulating):

- Concentration
- Contact time
- pH

Which of the following chemicals is not commercially used as a disinfectant?

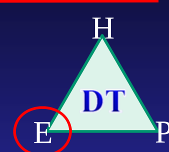
1. Chlorine
2. Ozone
3. Peroxide
4. Alcohol



Preventative Practices

Strategies of postharvest decay control for protection, suppression, or eradication of decay

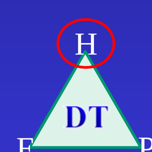
Altering the micro-environment



- pH: enzyme function, nutrient availability
- Fungicides: Direct toxicity
- Biocontrols: Competition, antibiosis, parasitism

Altering the host physiology

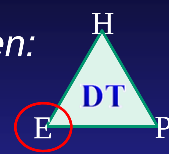
- Plant growth regulators (PGRs):
  - Examples - Gibberellin (citrus), 2,4-D (citrus), & Ethylene biosynthesis inhibitors
  - Effective against weak pathogens



Disease triangle

Altering the micro-environment

Treatments with indirect effects on the pathogen:



Disease triangle

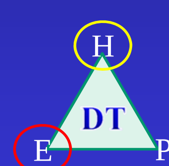
- Change in pH
  Accumulation of alkali in potential infection sites on fruit surface

Examples:

- Alkaline solutions of borax, sodium carbonate (soda ash), and sodium bicarbonate (baking soda) used on citrus
- Accumulation of acid in potential infection sites, (e.g. SO_2 used in storage of grapes)

Borax, sodium carbonate (soda ash), and sodium bicarbonate

- *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

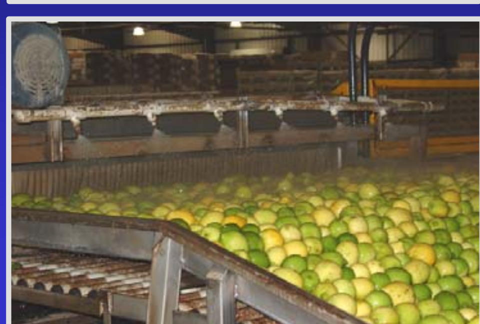


Disease triangle

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

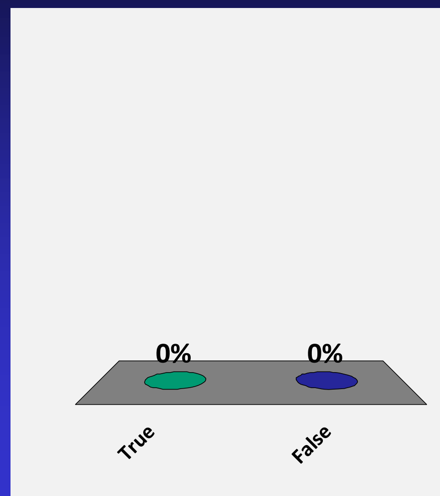
Treatment with heated soda ash



Water rinse after soda ash treatment

Sodium bicarbonate is commonly used in citrus packinghouses to protect wounds by shifting the pH to acidic conditions.

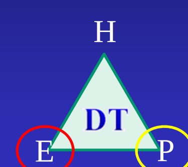
A. True
B. False



Altering the micro-environment

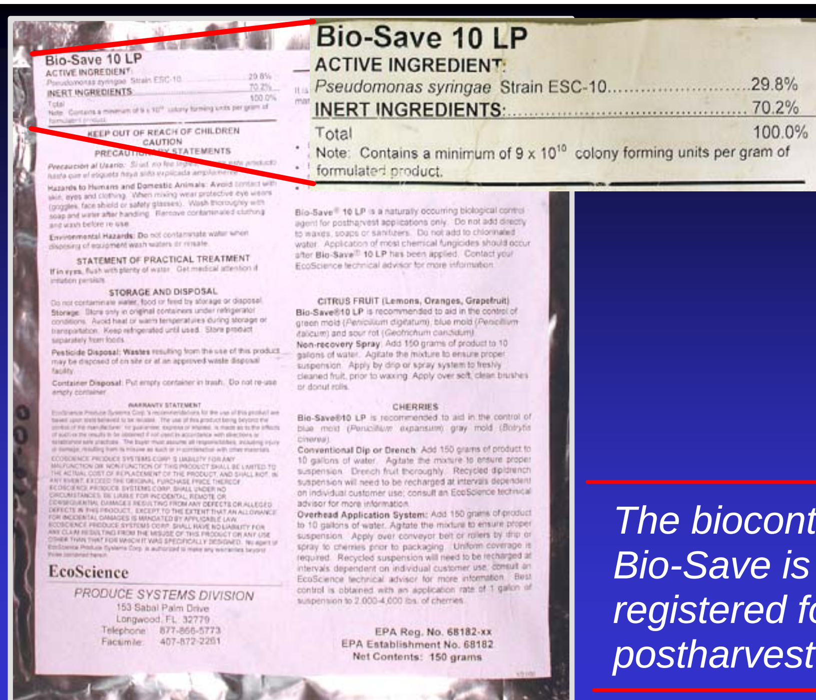
Treatments with direct effects on pathogen:

- 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 to 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 (no longer manufactured), *see* NEXY (*Candida oleophila*)
  - Bio-Save (*Pseudomonas syringae*), still in use



The biocontrol Bio-Save is registered for postharvest use

Spectrum of Activity of Biocontrols for Postharvest Decay Control

Biocontrol	Organism	Crops	Decays
Bacteria	*Pseudomonas syringae*	Apples, pears, citrus	Penicillium Decays
		Sweet cherry	Gray mold, Penicillium decays
Yeast	*Candida oleophila*	Pome fruit	Penicillium Decays
		Citrus	Penicillium Decays

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 such as Candifruit (*Candida sake)*, NEXY (*Candida oleophila)*, and Boni-Protect **(***Aureobasidium pullulans)* are in development.

Postharvest treatments approved for organic produce and their limitations

• Sodium bicarbonate	- Short-lived
• Calcium chloride and other chlorine products (with rates defined by OMRI)	- Only water and surface-disinfestation
• Diluted ethanol (not in the US)	- Highly regulated by government
• Heat	- Cost, damaging to some crops
• UV irradiation	- Cost, damaging to some crops
• Biocontrol agents	- Inconsistent in efficacy

Prevention, suppression, and eradiction of postharvest decays

Fungicides vs. biological controls

Fungicides	Biological controls
Single synthetic active ingredient	Mixtures of active and inactive ingredients. Active ingredient often unknown.
Well characterized chemically and toxicologically	Chemically and toxicologically often poorly characterized, but considered natural.
Efficacy generally high	Efficacy variable

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
- Classes are identified as FRAC groups (FRAC = Fungicide Resistance Action Committee)

Important older postharvest fungicides for citrus and pome fruits that are still being used today

Residual Fungicide	Class/Grouping	Crops	Decays
SOPP	Phenol	Citrus	Penicillium decay, sour rot
Thiabendazole	Benzimidazole	Citrus, pome fruit	Penicillium decay, gray mold
Imazalil	SBI-Imidazole	Citrus	Penicillium Decays

Towards safer postharvest decay control materials

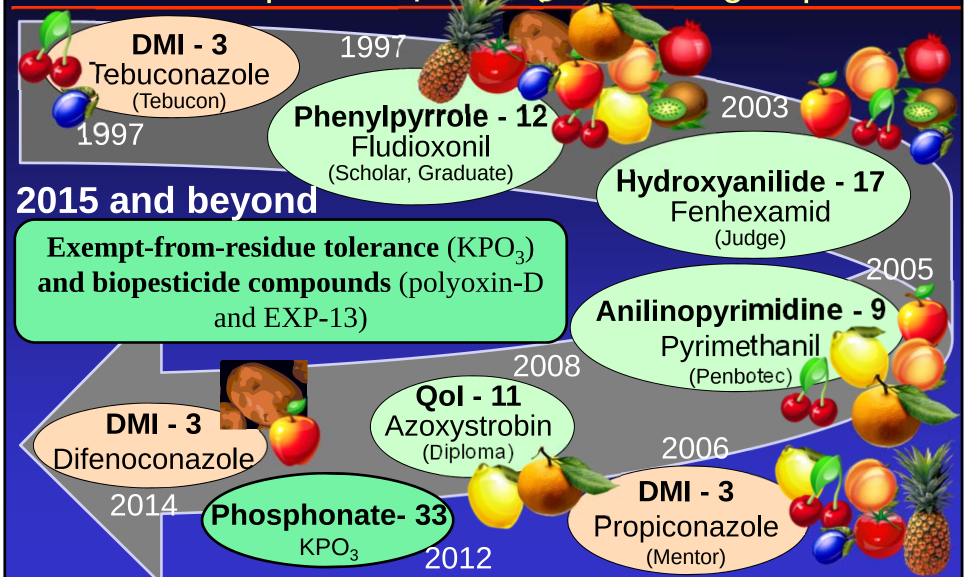
- Re-registration requirements of older pesticides
- Reduced Risk Pesticides (an EPA classification)
  - A relative term that is applied to a pesticide as compared to currently registered pesticides of a crop group.
  - A pesticide that broadens the adoption of IPM practices or reduces:
    - Exposure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

  Pesticides derived from natural materials such as animals, plants, bacteria, fungi, and certain minerals.

Benefits of postharvest reduced-risk fungicides to prevent decay

Untreated and postharvest treated (Scholar) peaches and sweet cherries

New-era postharvest fungicides for temperate and sub-tropical crops – Eight FRAC groups



Each oval is a unique mode of action (No. = FRAC No.). = Reduced Risk = Conventional

Spectrum of Activity of Registered and New Postharvest Fungicides on Selected Agricultural Crops in the US

Fungicide	Class	Crops	Decays
Tebuconazole	SBI-Triazole	Sweet cherry	Brown rot, Rhizopus, and Mucor decays
Fludioxonil	Phenylpyrrole	Stone fruit*, pome fruit* Pomegran.*, kiwifruit* citrus*, Pineapple, tuber crops	Brown rot, gray mold, Rhizopus Rot, Penicillium decays
Azoxystrobin	QoI	Citrus*, potato	Penicillium decays
Fenhexamid	Hydroxyanilide	Stone fruit pome fruit, pomegranate, kiwifruit	Brown rot, gray mold
Pyrimethanil	Anilinopyrimidine	Stone fruit, pome fruit, citrus*	Penicillium decays, brown rot, gray mold
Difenoconazole	SBI-Triazole	***Pome fruit, tuber crops***	Penicillium decays, Bull's eye rot Rhizopus rot
Propiconazole	SBI-Triazole	Stone fruit, citrus, tomato, pepper	Penicillium decays, brown rot, gray mold, sour rot

Fungicide is already registered; * - FAT approved in Japan.
new registrations or proposals are in bold italics

Controversy on the use of fungicides as postharvest treatments to fruit crops

- In many countries, fungicides are commonly applied before harvest in the field to prevent postharvest fruit decays – applications are done as late as 1 day before harvest.
- In contrast, postharvest use of fungicides to food crops is not widely accepted in all countries.
- Considerations:
  - The same or similar fungicides may be used pre- and postharvest.
  - Residue levels on the crop are similar for both application methods and are subject to the same residue limits.
  - Postharvest applications are generally more effective because they are more targeted. They also have a lower impact on the environment (smaller carbon footprint).

Preventing fungicide resistance in the postharvest environment

Guidelines in postharvest fungicide registrations: *Pre-mixtures or tank mixtures of different classes*

With mixtures, the resistance potential is much reduced:

Res. frequency compound A	x	Res. frequency compound B	=	Res. frequency Pre-mix AB
Example: 10^6	x	10^9	=	10^{15}

Mixtures of two or three active ingredients that belong to different chemical classes are critical in the prevention of fungicide resistance in target populations.

Postharvest fungicide pre-mixtures

DMI Imazalil + **Anilinopyrimidine** Pyrimethanil = **Philabuster** Citrus

Phenylpyrrole Fludioxonil + **QoI** Azoxystrobin = **Graduate A+** Citrus

Phenylpyrrole Fludioxonil + **DMI** Propiconazole = **Chairman** Stone Fruit, Tomato, Pineapple

Phenylpyrrole Fludioxonil + **MBC** TBZ = **Scholar Max MP** Pome fruit - registered

Phenylpyrrole Fludioxonil + **DMI** Difenoconazole + Azoxy-strobin = **Stadium** Potato

and others ….

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

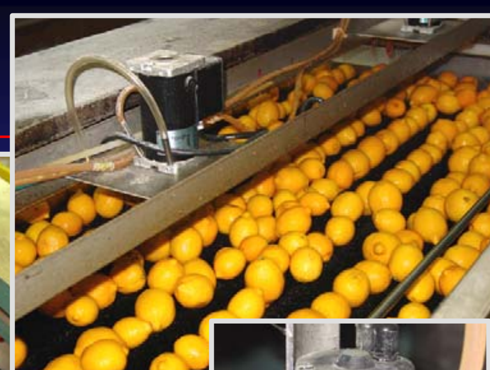
- High volume applications: 100-200 gal/ton of fruit
- Low volume applications: 8-30 gal/ton of fruit

Low volume application and recycling drench application systems have become more popular because of very little run-off and disposal problems. Recycling drench applications are superior in efficacy.

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

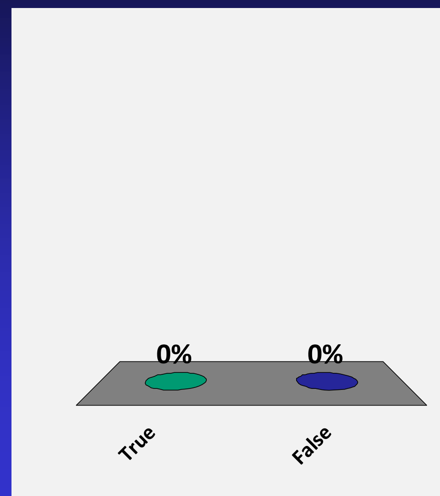
Application methods for postharvest fungicide treatments

Fogging

Fungicide application methods determine coverage and this is important for optimum decay control

A. True

B. False



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
  - Increased shine of fruit

Common fruit coatings used in postharvest treatments

	Characteristics			Use on specific crops			
Type of wax	Prevention of water loss	Gas exchange	Shine of fruit*	Citrus	Nectar./ Peach/ cherry	Plum	Pome
Mineral oil non-emulsified	+++	+	+++		+	+	
Mineral oil emulsified	++	++	+++		+	+	
Polyethylene	+++	+++	+++	+			
Vegetable oils	++	++	++		+	+	
Carnauba	+++	+++	++	+	+	+	+
Shellac	+	+/-	+++	+			+
Wood rosin blends	+	+/-	+++	+			

- 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.

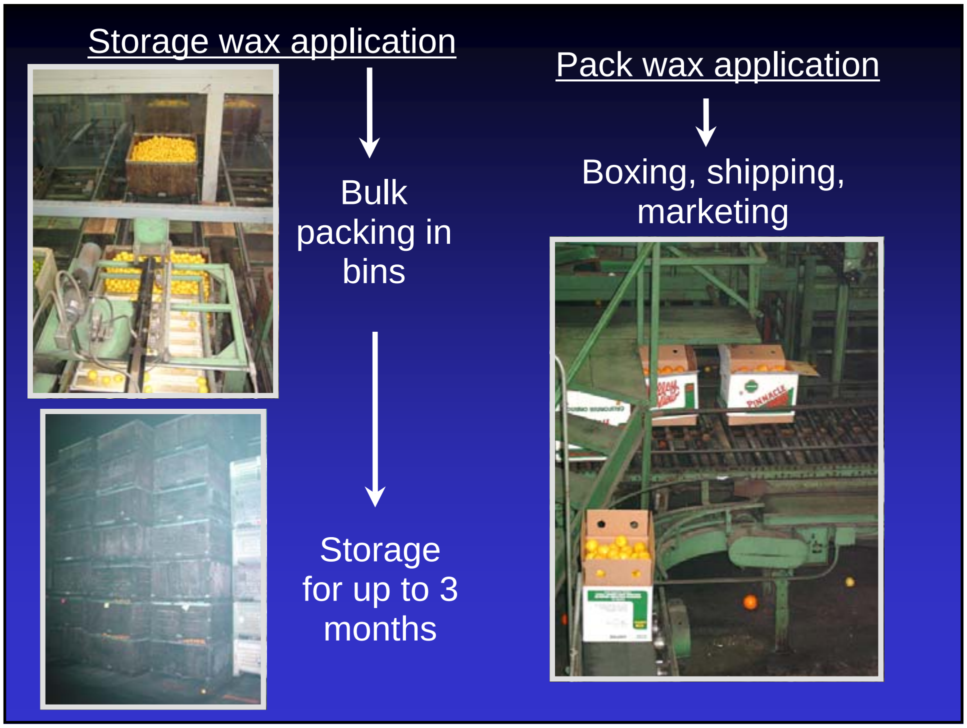
Postharvest fungicide treatments as a component of postharvest handling
Example: Lemons in California

Fruit arrival

→ Sorting

Chlorine wash, soda ash treatment, water rinse

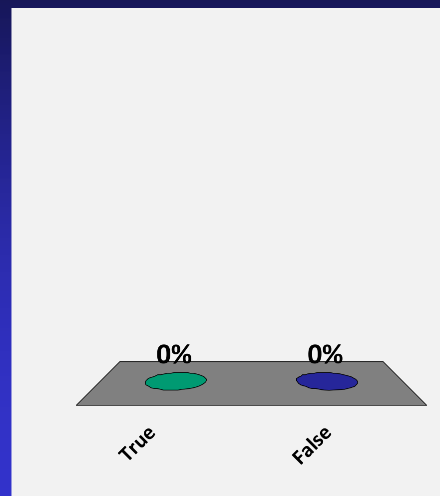
Application of fungicide and fruit coating


Storage wax application
Bulk packing in bins
Storage for up to 3 months
Pack wax application
Boxing, shipping, marketing


Chlorine wash after storage
Sorting
Fungicide and pack wax application
Boxing and marketing

Postharvest fruit coatings improve sugar content and water loss

A. True
B. False



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

Graduate (fludioxonil) MRLs in major export markets:

	Lemon	Orange	Grapefruit	Tangerine
US	10	**10**	**10**	**10**
CODEX	10	**10**	**10**	**10**
EU	7	**7**	**10**	**7**
Japan FAT	10	**10**	**10**	**10**
Korea	5	**5**	**10**	**1**
Australia	10	**10**	**10**	**10**
Taiwan	7	**5**	**5**	–
Following CODEX:	Hong Kong	Hong Kong	Hong Kong	Hong Kong
	India	India	India	India
	Malaysia	Malaysia	Malaysia	Malaysia
	New Zealand	New Zealand	New Zealand	New Zealand
	Philippines	Philippines	Philippines	Philippines
	Singapore	Singapore	Singapore	Singapore
	Thailand	Thailand	Thailand	Thailand

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

- *R*otate between fungicide classes
- *U*se labeled rates
- *L*imit the total number of applications
- *E*ducation of spectrum of activity
- *S*anitation is essential in an integrated management program

Regulation of pesticide usage

- Product being used has to be registered.
- Pest control advisor must make a written recommendation.
- Usage of a pesticide has to be reported to the county Agricultural Commissioner's office and state regulators.
- Residues are periodically monitored in fruit lots by:
  - Packinghouse personnel
  - Importers
  - Buyers
- Fruit lots that exceed the MRL of any pesticide must be destroyed.

Use limits of pesticides

- ***Residue tolerances*** must be established for all postharvest chemical treatments except for those that are:
  - EPA – ***Exempt*** designation or
  - FDA – ***GRAS*** (Generally Regarded as Safe) designation
  Examples : chlorine, potassium sorbate, sulfur
- ***Residue tolerances - Maximum residue limits (MRLs)***
  = The highest amount 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

Fungicide	MRL	LD_{50} rat
Fludioxonil	Stone fruit: 5 mg/kg	>5000 mg/kg
Fenhexamid	Stone fruit: 10 mg/kg	>2000 mg/kg
Pyrimethanil	Citrus: 7 mg/kg	>5000 mg/kg

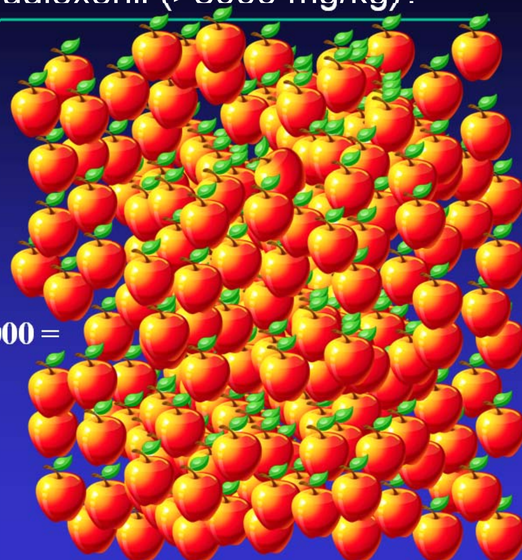
mg/kg = ppm

Remember that these are maximum levels and actual residue levels are just fractions of values needed 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 =



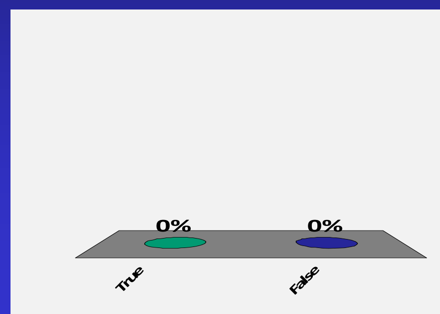
50,000 apples/Kg x Body weight (70 kg for an adult)=3.5 million apples!

If you are still concerned….

- **Wash your fruit!** (Most fungicides are not systemic and can be removed with a household rinse)

Fungicides for postharvest decay control are selected based on their safety and efficacy. They are used to ensure that wholesome and nutritious fruit are delivered to worldwide markets.

A. True
B. False



Useful Publications - Books:

Postharvest Technology of Horticultural Crops

3rd Edition ANR Publication No. 3311. 2002
Edited by A. A. Kader

Postharvest Pathology

1st Edition Springer, New York, 2010
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

A. L. Snowdon, Wolfe Scientific, 1990

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/opprd001/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):
http://www.jbtfoodtech.com/solutions/equipment/fresh-produce-technologies/post-harvest-products-and-services.aspx

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/