Warning

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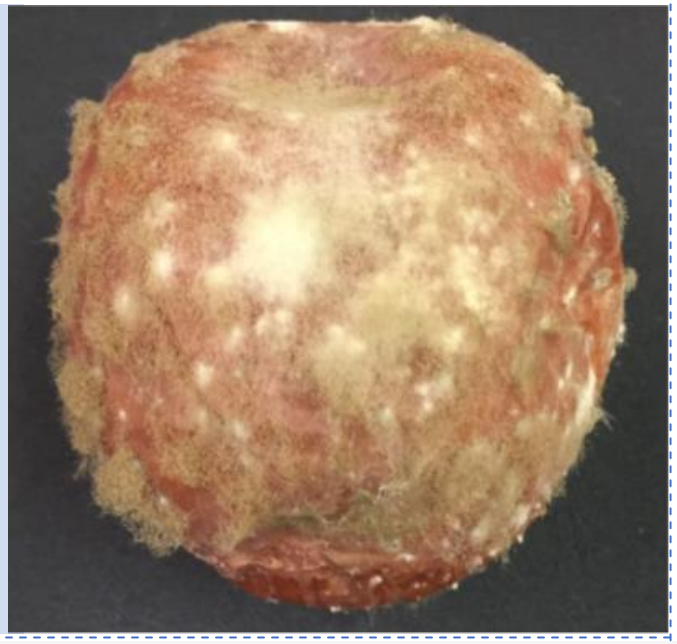
Pre & Postharvest Disease Management Workshop

March 4th, 2020

Achour Amiri, WSU Plant Pathology

Module I

Part 1: Overview and Occurrence of Major Postharvest Diseases

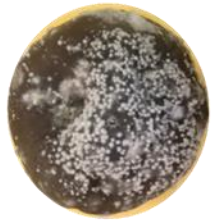


Kutay Ozturk and Achour Amiri, WSU Plant Pathology

Learning Objectives

- Acquire knowledge about the most important pathogens causing fruit rots
- Know their occurrence in Washington and the Pacific Northwest
- Better understand how these pathogens infect fruit
- Identify key diseases
- Acquire knowledge about quarantine pathogens




Quiz

1- How many fungal pathogens are reported to cause decay on pome fruit?

- ❑ 12
- ❑ 38
- ❑ 100
- ❑ 312

2- How many of these 100 cause economic losses?

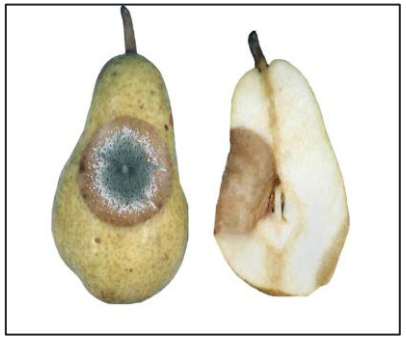
- ❑ 3
- ❑ 10
- ❑ 19
- ❑ 51




Blue Mold:
Penicillium expansum, *Penicillium* spp.

1. Major threat: # 1 disease ~$5M annual loss

2. Airborne & wound-pathogen
3. Soft tan to light brown lesion with green spore masses

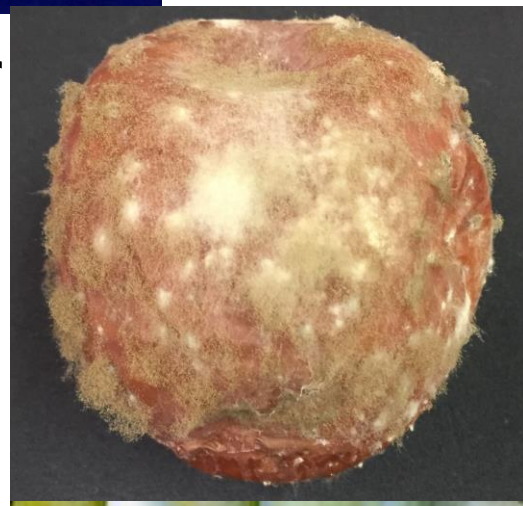


4. Some species: Pharmaceutical and food industries
5. Mycotoxin in processed apples & pear

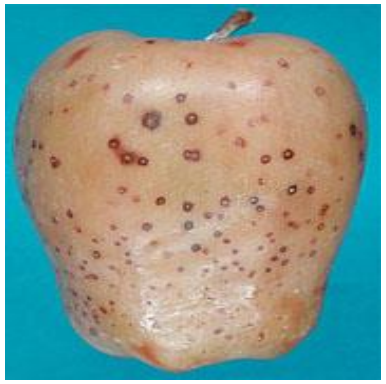



Gray Mold:
Botrytis cinerea,
Botrytis mali?

1. Big threat: # 2: apples, # 1 or 2: pear
2. Latent and wound-pathogen
3. Survives in mummies and organic matter
4. Spongy brown lesion-gray mycelium
5. Nests in storage bins








Speck & Phacidiopyc-nis rot

Phacidiopycnis washingtonen-sis, P. pyri

1. Emerging threats: # 3 or 4 for loss
2. *P. washingtonensis* (Apple) and *P. pyri* (Pear)
3. Calyx-stem ends, and wound-pathogens
4. Survives on crabapples, cankers, dead twigs
5. Firm lesion with specks, or water-soaked margins, black tissue as decay advances
6. Quarantine in some countries e.g. China

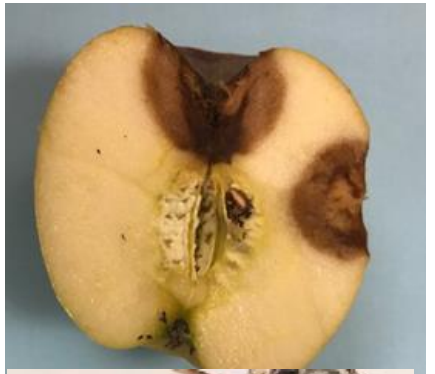





Bull's eye rot

Neofabraea spp.

1. Challenging: # 3 or 4 for losses
2. Four species: *Neofabraea perennans*, *N. malicorticis*, *N. alba*, *N. kienholzii*
3. Infections through lenticels and stem-bowl
4. Cause anthracnose and perennial cankers on trees: overwinters
5. Brown sunken lesions with creamy-spores
6. Current cultivars: vary in susceptibility
7. Preharvest rain or wetness increase risks





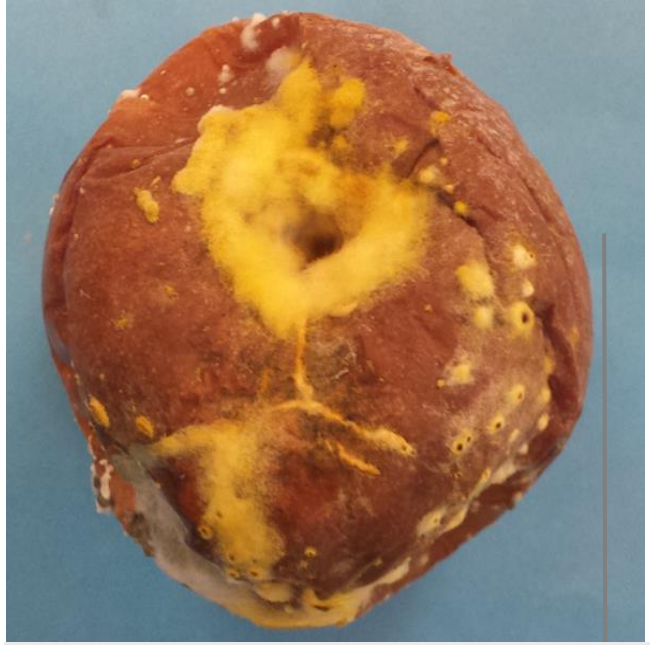



Mucor rot

Mucor pyriformis, Mucor spp.

1. Risky threat: Ranked # 4 for losses
2. Wound pathogen, survives in soil/bins/dump tanks
3. Causes a very soft juicy brown lesion
4. None of current fungicides are effective
5. Does not nest in storage bins but can break (too soft) and spread easily


Other secondary diseases



Lambertella rot*

Alternaria rot

* Quarantine

Sphaeropsis rot*

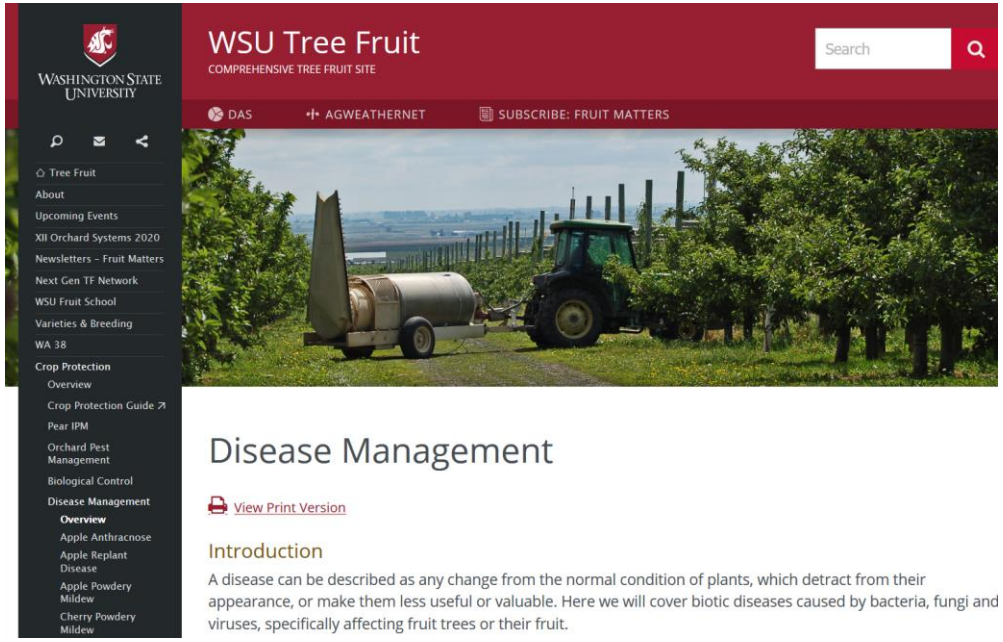
Nectria rot *

Summary

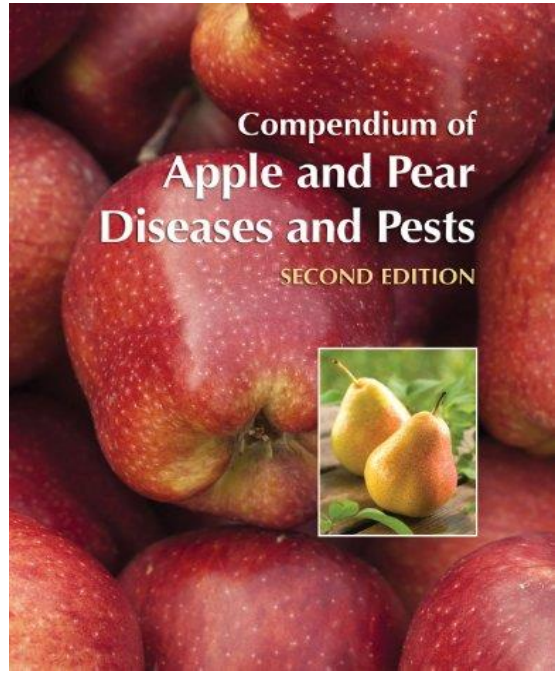
- About 100 fungi can infect pome fruit
- About 10 pathogens can cause economic losses
- Blue mold and Gray mold are the two most important postharvest rots
- Three quarantine pathogens may be of concern at export
- Apple and pear processors should be aware of potential mycotoxin-related issues

Additional sources

- Factsheets provided in the packet
- WSU TREE FRUIT: http://treefruit.wsu.edu/



- Compendium of apple & pear disease



Additional sources

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WSU-Extension Team

Module I

Part 2: Inoculum Sources & and Infection Timeline

Learning Objectives

- Notion of pathogen versus disease (decay/rot)
- Infection timeline of fruit by major pathogens
- Factors that may exacerbate infections
- Acquire and apply knowledge to assess and anticipate infection risks

Economics of fruit decays

$~3B

$~0.5B (organic)

$~4B

$0.5B

Fruit losses (%)	Economic impact ($M)
0.1	-4
0.5	-20
1.0	-40
5.0	-~200

Major diseases and their causal pathogens: Pre and postharvest

Disease	*Pathogen*	Importance in PNW
1. Fire blight	*Erwinia amylovora*	++++
2. Blue mold	*Penicillium expansum*, spp.	++++
3. Gray mold	*Botrytis cinerea*	+++
4. Speck rot	*Phacidiopycnis* spp.	++
5. Powdery mildew	*Podosphaera leucotricha*	++
6. Mucor rot	*Mucor piriformis*	++
7. Bull's eye rot	*Neofabraea* spp.	++
8. Alternaria rot	*Alternaria alternata*	++
9. Sphaeropsis rot	*Sphaeropsis pyriputrescens*	+
10. Yellow rot	*Lambertella corni-maris*	+
11. Other Rots	Multiple species	+

Diseases and their causal pathogens: Symptoms vs. Infections

Disease name	*Pathogen name*	Symptoms visible	Infection occur
1. Fire blight	*Erwinia amylovora*	Orchard	Orchard
2. Powdery mildew	*Podosphaera leucotricha*	Orchard	Orchard
3. Gray mold	*Botrytis cinerea*	Warehouse	Orchard
4. Speck rot	*Phacidiopycnis spp.*	Warehouse	Orchard
5. Bull's eye rot	*Neofabraea spp*	Warehouse	Orchard
6. Alternaria rot	*Alternaria alternata*	Warehouse	Orchard
7. Sphaeropsis rot	*Sphaeropsis pyriputrescens*	Warehouse	Orchard
8. Yellow rot	*Lambertella corni-maris*	Warehouse	Orchard
9. Mucor rot	*Mucor piriformis*	Warehouse	Warehouse*
10. Blue mold	*Penicillium expansum*	Warehouse	Warehouse*

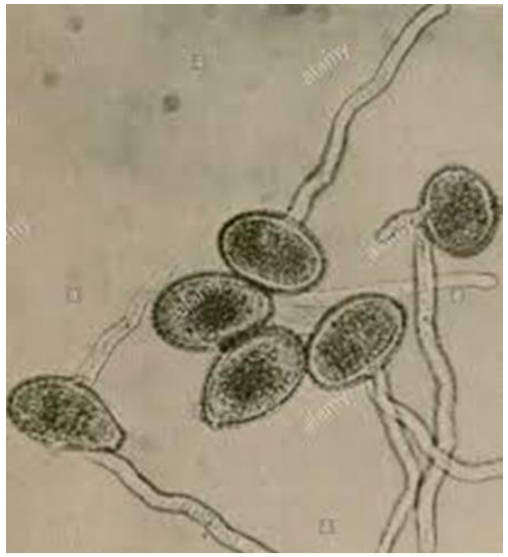
Marginal infections may occur close to harvest

Pathogens

- Fall & Winter: Where do fungi go?
- Spring: What changes for the pathogens?
- What are the main sources of inoculum?
- How infections start and progress during the growing season?
- What Factors may exacerbate infections?
- How infections progress in cold storage?

How fungi survive in orchards ?

Normal conditions



Spores & Mycelia

Organic matter, free water, mummies, cankers

Harsh conditions

Sclerotia

Sexual reproduction

Fruiting bodies

Rare

What happens to pome fruit pathogens in fall and winter?

Most pathogens undergo a dormancy:

1. In buds (Mildew)

2. As sclerotia (Botrytis-Gray mold, Alternaria)

3. Cankers, dead wood, dead twigs, mummies, crabapples, organic matter: *Neofabraea* (bull's eye rot *Phacidiopycnis*, *Sphaeropsis*

What happens to pome fruit pathogens in spring and summer?

Fungi require three main factors to cause infections

		Conditions in Central WA during	
Factor	Range	Spring	Summer
Temperature	Min-Optimal-Max	Mostly Optimal	May limit some fungi >90°F
Nutrients	Vary by fungi	Depends on orchard management*	Depends on orchard management
Moisture	Moister the better	Near-optimal	Dry: Disadvantageous ?

* Orchard management: Natural habitats removal: Mummies removal, pruning cankers and crabapples, orchard floor & weed management.

Inoculum sources of major rot pathogens

Disease	*Pathogen*	Inoculum sources
1. Blue mold	*Penicillium expansum*	Bins, rooms, flume water, soils
2. Gray mold	*Botrytis cinerea*	Mummies, dead leaves
3. Speck rot	*Phacidiopycnis spp.*	Crabapple pollinizers, dead twigs
4. Mucor rot	*Mucor piriformis*	Soils, dead leaves, bins
5. Bull's eye rot	*Neofabraea spp*	Cankers, dead wood
6. Alternaria rot	*Alternaria alternata*	Mummies, dead leaves
7. Sphaeropsis rot	*Sphaeropsis pyriputrescens*	Cankers, dead wood & bark, dead twigs
8. Yellow rot	*Lambertella corni-maris*	Unknown, mummies?

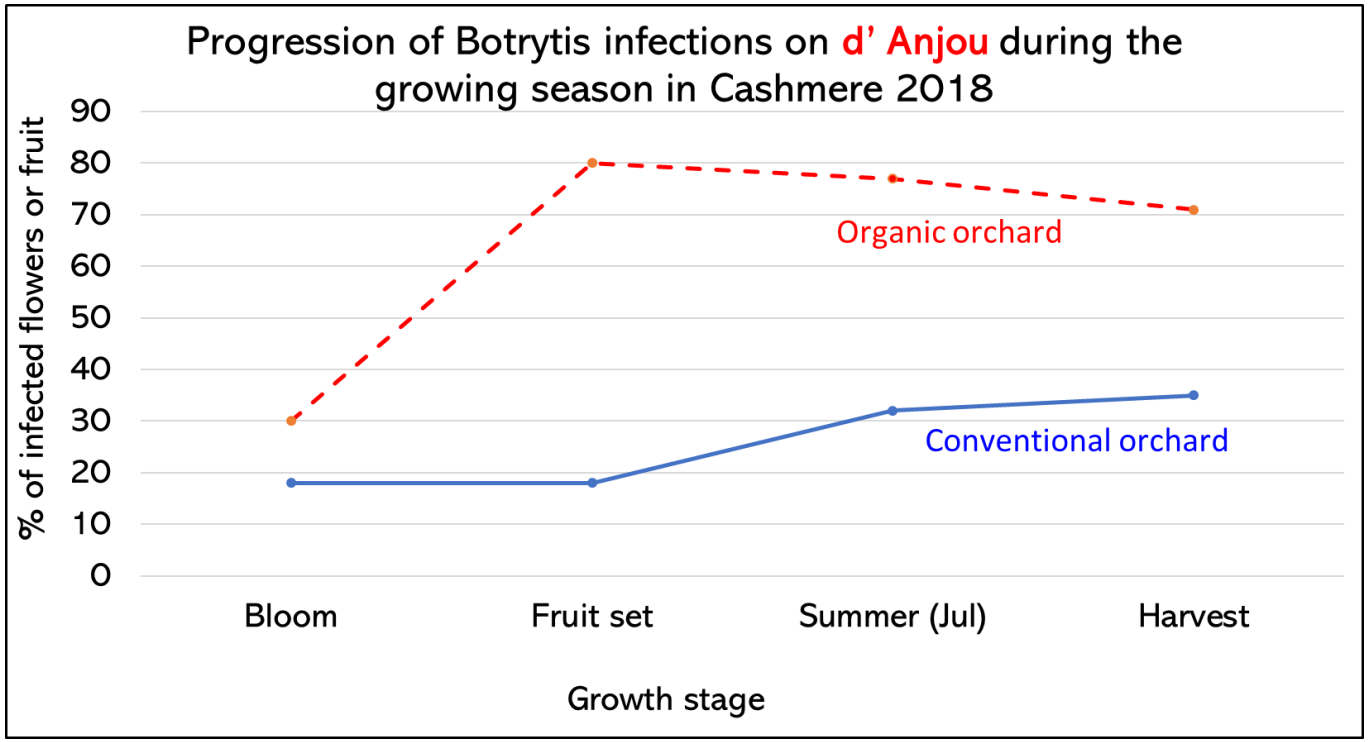
Research

Current knowledge about infections caused by some rot pathogens:

- *Botrytis* (Gray mold)
- *Neofabraea* (Bull's eye rot)
- *Phacidiopycnis* (Speck rot)
- *Penicillium* (Blue mold)

Botrytis cinerea (gray mold) infections in the orchard

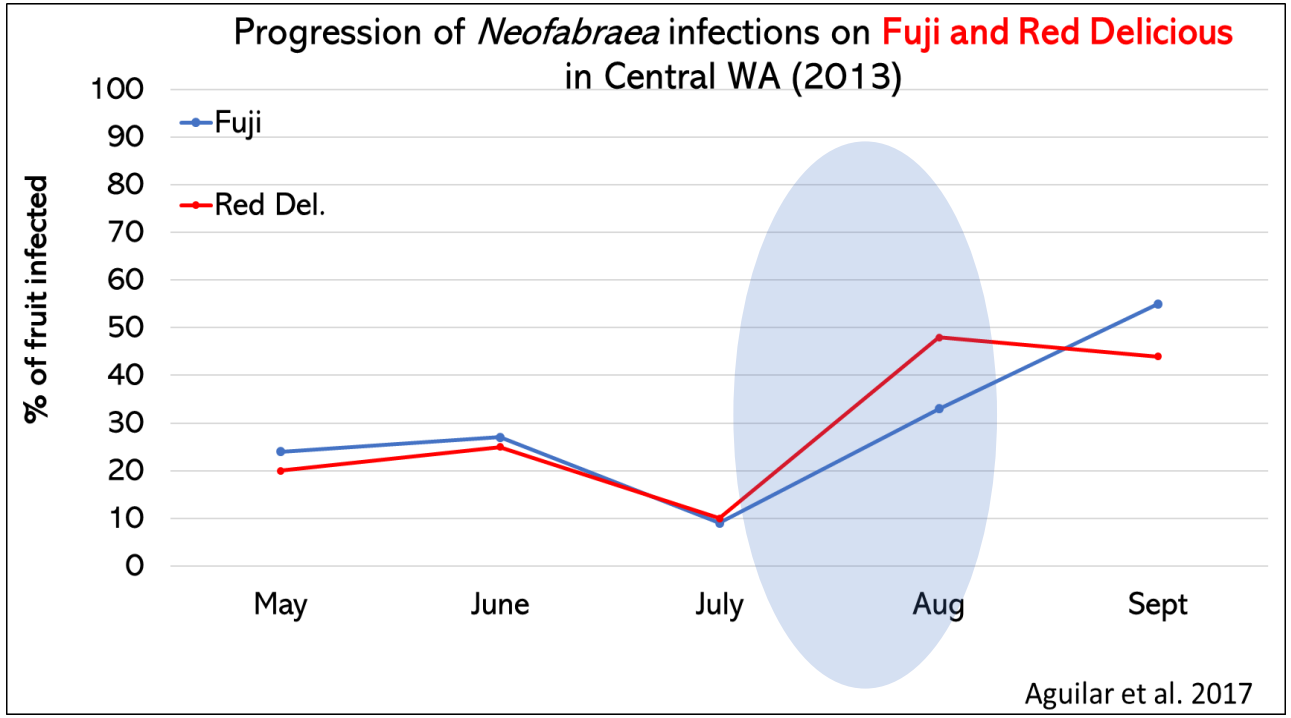
- Optimal temperature: 20-25°C (68-77°F), Slows down >91°F
- Wetness duration: 6-14 h



How can we use this information to improve management? (Module 2)

Neofabraea spp. (bull's eye rot) infections in the orchard

- Optimal temperature: 20°C (68°F), Slows down >88°F
- Wetness duration: 6 h

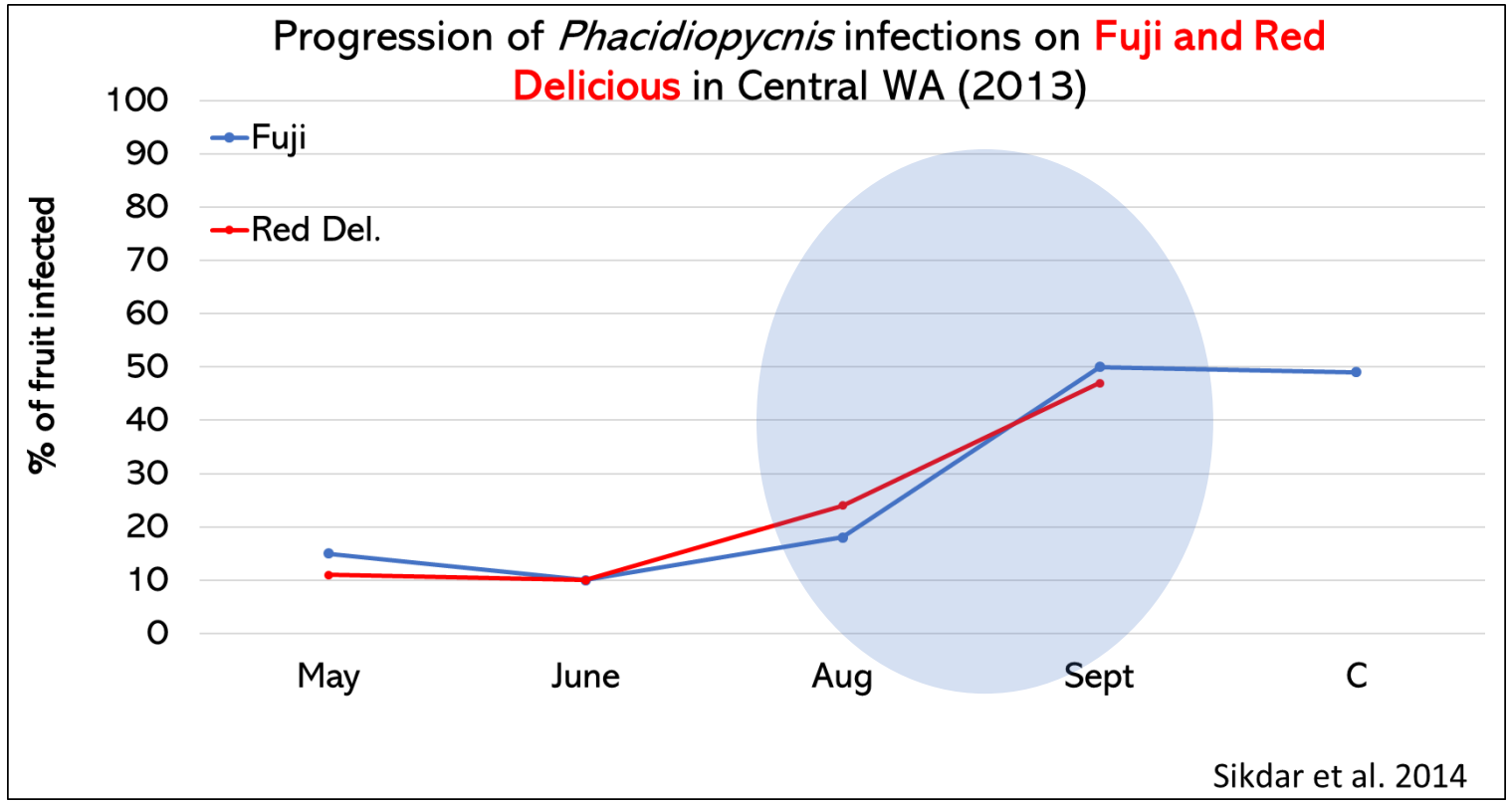


Apple cultivars: Vary in their susceptibility to *Neofabraea*, trend may vary but overall similar

Pear cultivars: Not much known but d' Anjou are susceptible

Phacidiopycnis spp. (speck rot) infections in the orchard

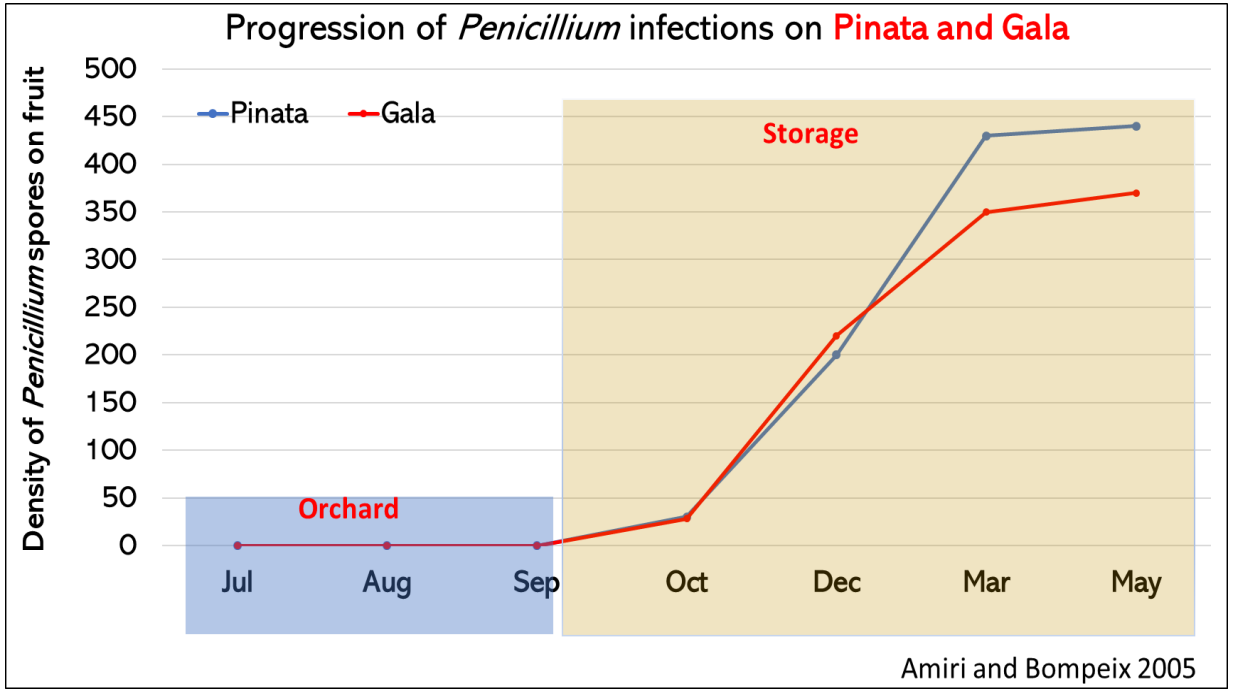
- Optimal temperature: 20-25°C (68-77°F), Slows down >93°F
- Wetness duration: 6 h

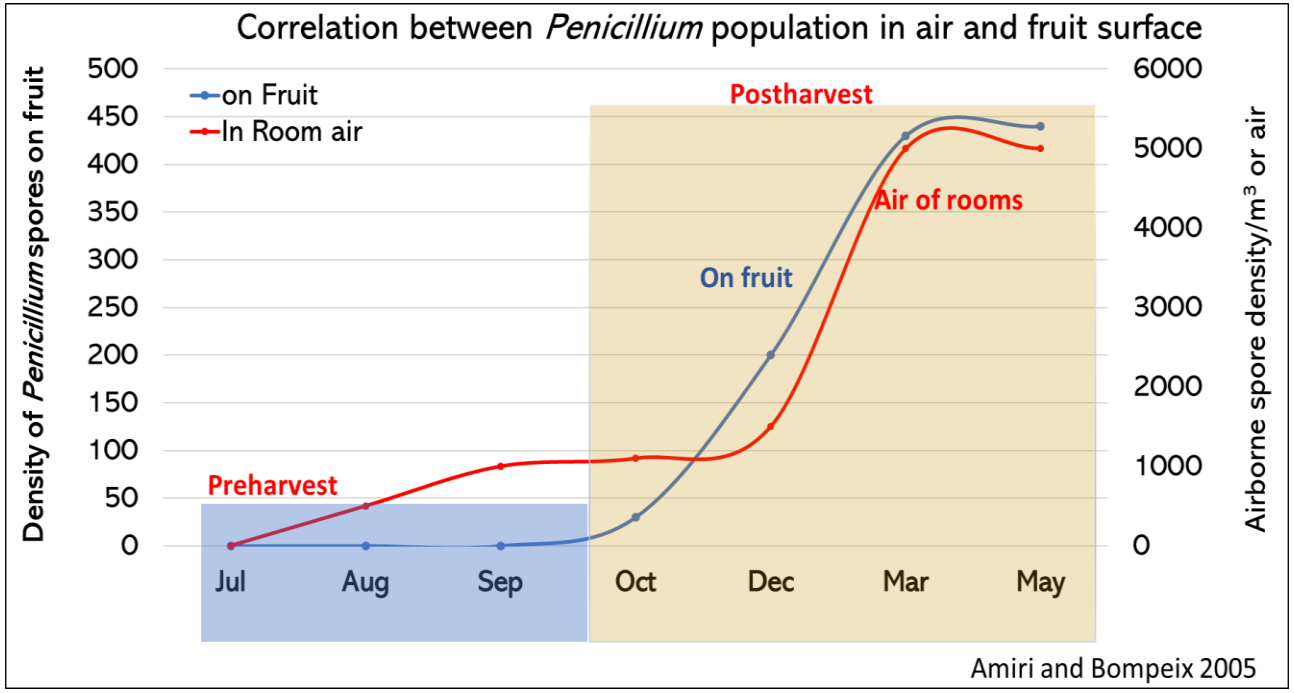


Apples: Pruning and removing mummies form pollinizers (es. Manchurian crabapples) is key, use other cultivars in new plantings

Pears: Origin still not fully known, **forest trees?**

Penicillium spp. (blue mold) infections from orchard to warehouse



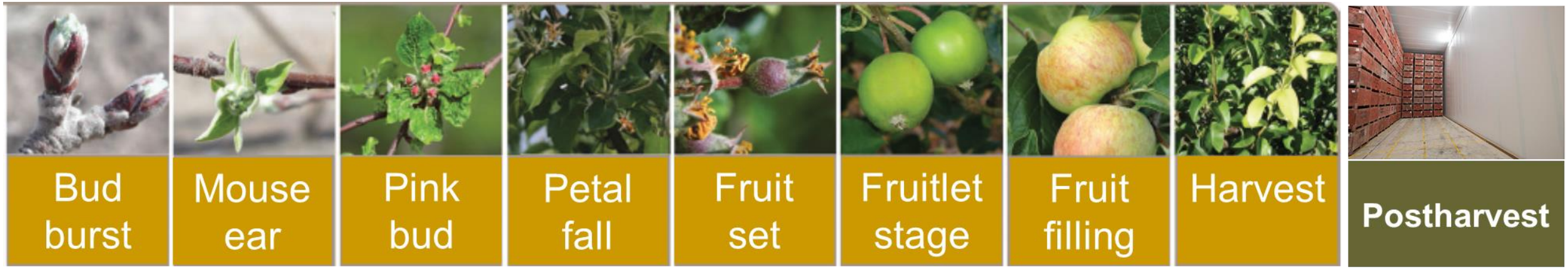


Bin/airborne populations

Fruit

Various relationship

Key timing of pathogen infections in the orchard



Podosphaera leucotricha **(Mildew)**

Erwinia amylovora **(Fire blight)**

Alternaria alternata **(Alternaria rot)**

Botrytis cinerea **(Gray mold)**

Neofabraea spp **(Bull's eye rot)**

Phacidiopycnis spp. **(Speck rot)**

Sphaeropsis pyriputrescens

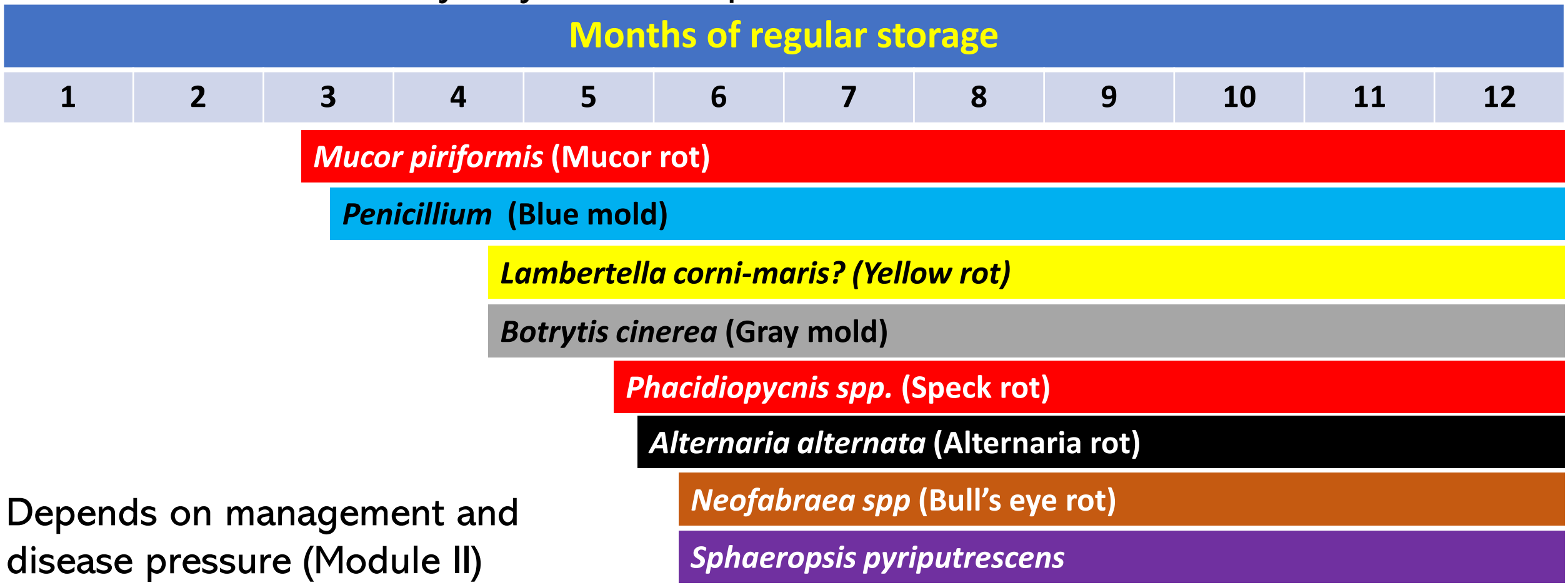
Lambertella c-maris? (Yellow R)

Penicillium **(Blue M)**

Mucor piriformis

Progress[1] of decays after harvest in regular storage

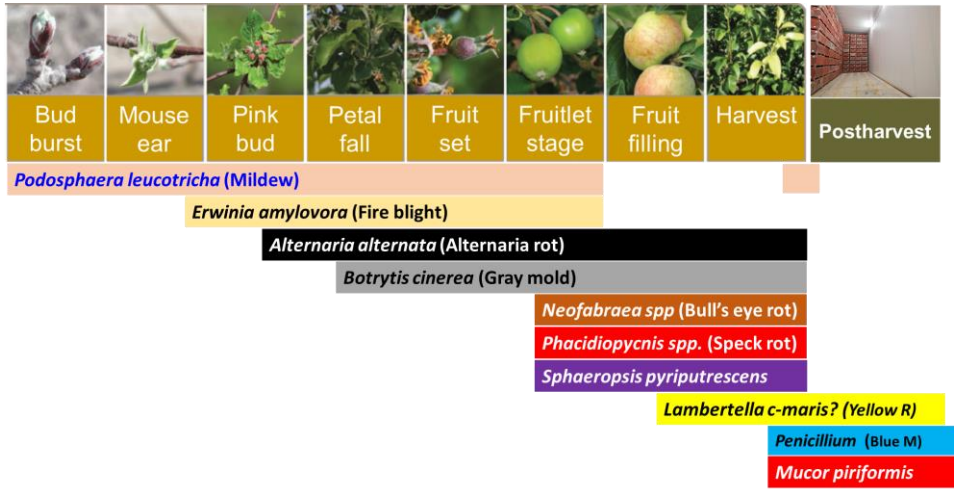
[1] how fast they may become a problem

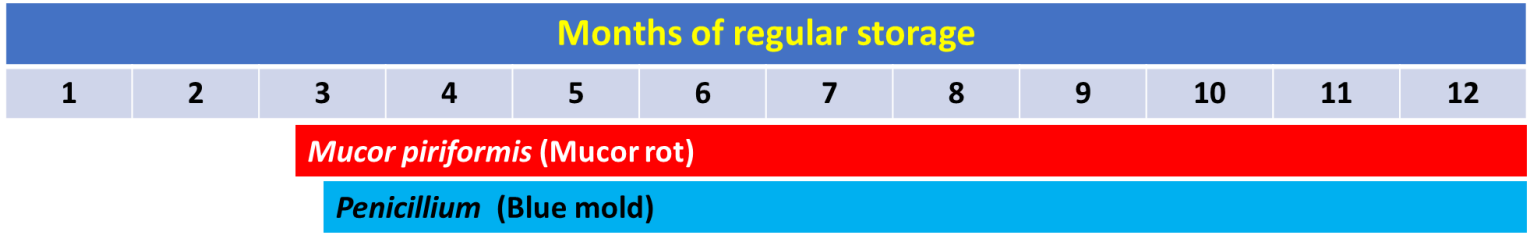


Depends on management and disease pressure (Module II)

Growth in CA or ULO may be slightly further delayed

Relative growth of infections in regular storage





Why *Penicillium* and *Mucor* are faster in cold storage although they infect fruit later ?

- Wound pathogens: infections progress faster on wounds
- Inoculum more available
- Better-adapted (virulent) to cold temperatures

Infection timeline: bottom-line

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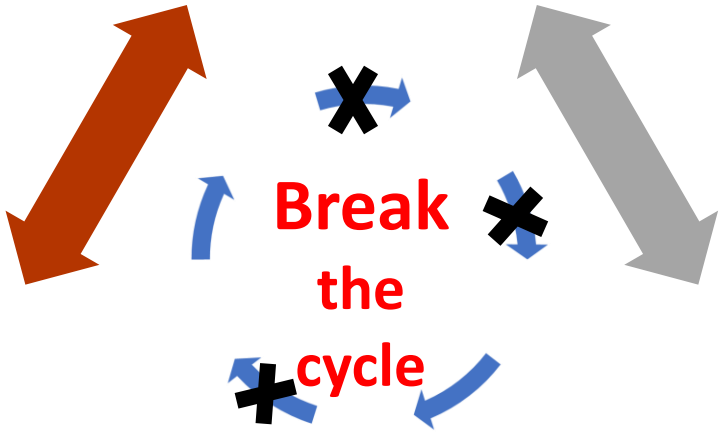
If no sanitation & effective sprays in the previous season → **Inoculum present in spring**



If no timely spring sprays in the following season

Infections start in spring and increase as fruit mature

If no timely summer sprays

More fruit will carry the inoculum to storage rooms

A cleaner fruit at harvest is less likely to decay in storage

How is this knowledge beneficial for decay control?

Impact

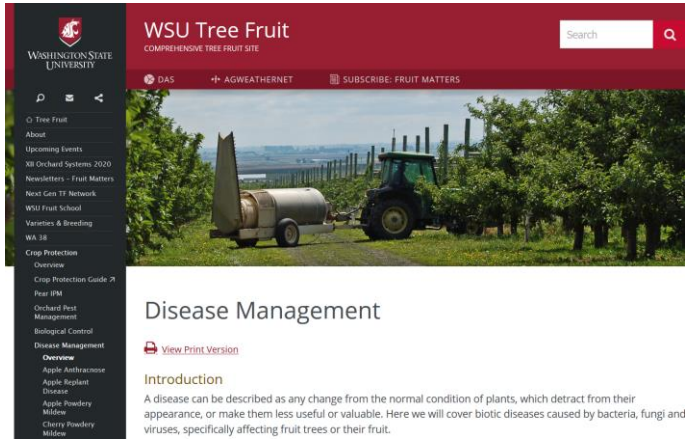
- Anticipate when infections are likely to occur
- Know how infections may evolve during the season and in storage: when to expect decay to become a real problem
- Factors that may exacerbate infections
- **To optimize management**: Module II

Summary

- 80% of pome fruit infections occur in the orchard
- Pathogens survive in different ways in orchards and warehouses
- Pathogens infect fruit at different growth stages
- Infections may slow down in warm weather then pick-up and continue through harvest
- Good sanitation and timely sprays will break-up infection cycles
- Cold storage slows down but does not fully stop infections

Additional Resources

- Factsheets provided in the packet: Disease cycles
- WSU TREE FRUIT: http://treefruit.wsu.edu/



- PNW Plant Disease Management Handbook https://pnwhandbooks.org/plantdisease

- Postharvest Center http://postharvest.ucdavis.edu/

Module II

Best Management Practices

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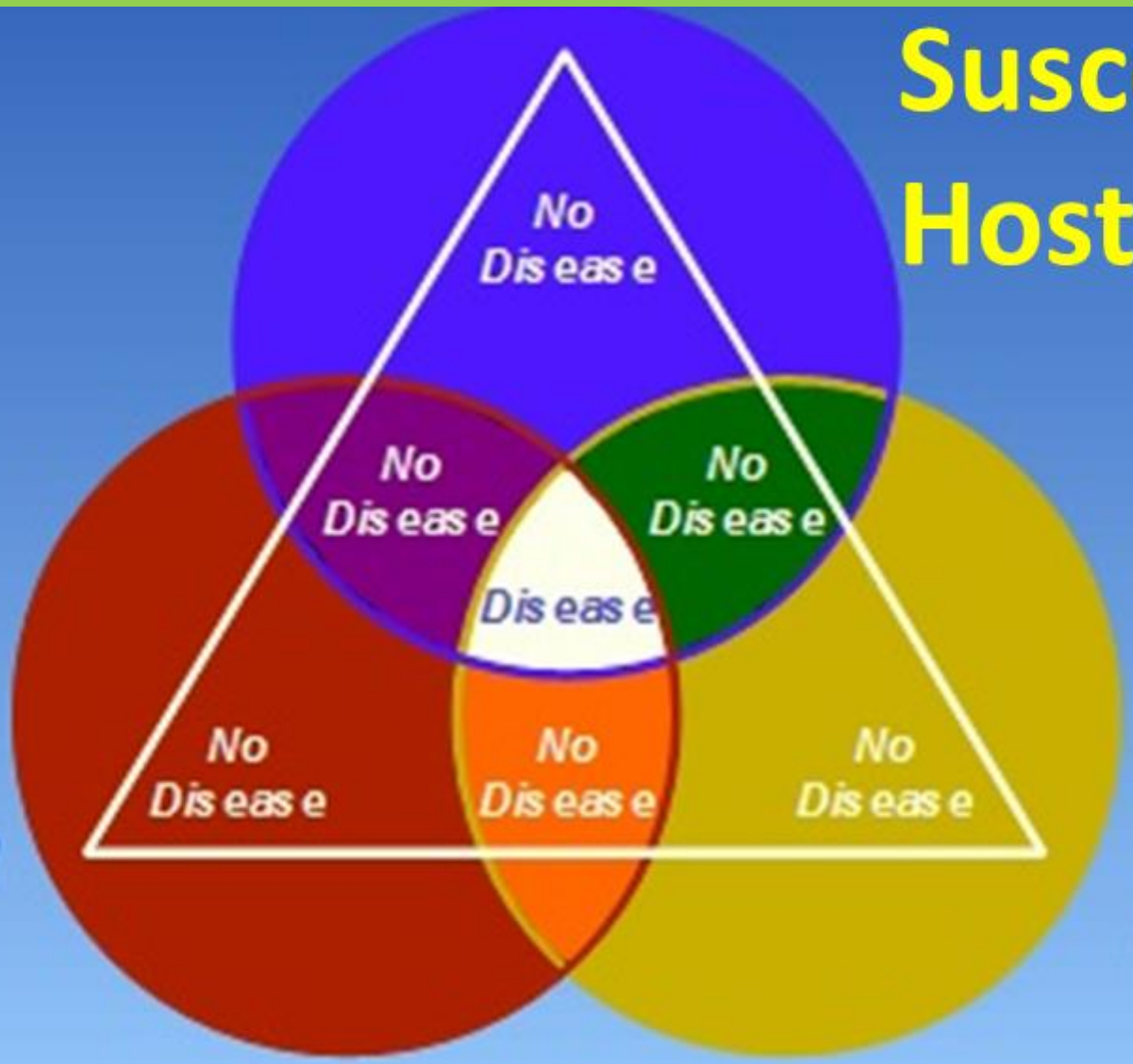
Tianna DuPont, WSU Extension

Disease Triangle



Cultivar Susceptibility

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2: lowest susceptibility
6: highest susceptibility

	Disease severity index				
Cultivar	**Blue mold**	**Gray mold**	**Bull' eye rot**	**Mucor rot**	**Epidermis strength**
Fuji	5	3	2	4	6
Braeburn	3	5	4	6	5
Golden Del	5	4	4	4	2
Empire	4	6	5	5	-
Jonagold	5	4	6	4	2
Royal Gala	2	3	6	1	4
Granny Smith	3	3	4	6	6

Spotts et al. 1999

Long term goal = resistance to postharvest diseases

Resistance genes to blue mold

- **Wild apple:** *Malus sierversii* (central Asia)
- Ongoing research (USDA-ARS-East Coast)

Wisniewski et al. 2011

General Management Concepts

Optimized Disease Management **SHOULD** include:

1. Appropriate preharvest cultural practices
2. Appropriate preharvest spray program
3. Timely preharvest sprays
4. Appropriate postharvest sanitation practices
5. Appropriate postharvest fungicides

Pre-harvest Sanitation

Mummies

Source for:

- Gray mold
- Mucor
- Alternaria

Pre-harvest Sanitation

Cankers

Source for

- Bull's eye rot
- Speck rot

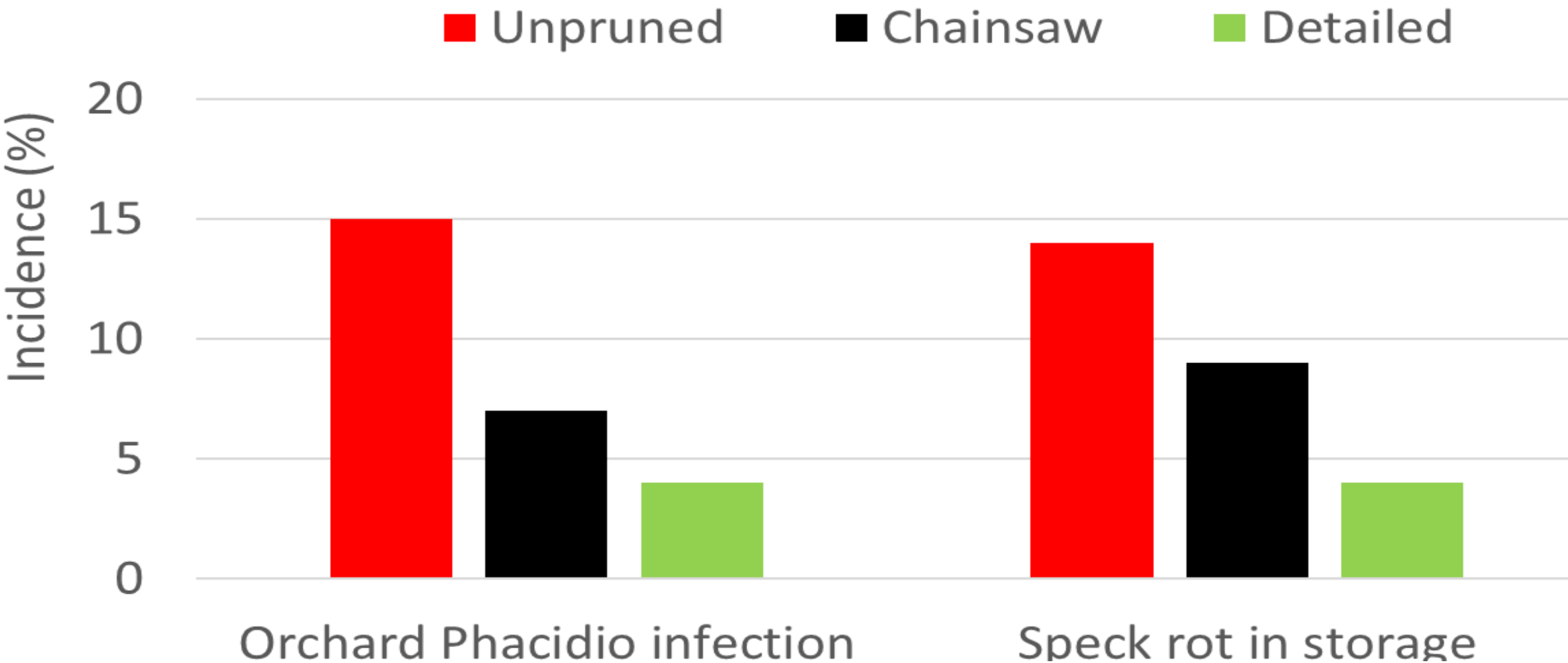
Pre-harvest Sanitation

Crab apple Pollinizers

Source for:

- Speck rot
- Sphaeropsis
- Alternaria

Pruning crabapples can reduce speck rot



Pre-harvest Sanitation

Orchard Floor/ Irrigation Water

Source for:

- Gray mold
- Mucor
- Alternaria
- Phytophthora

Pre-harvest Sanitation

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How much inoculum (spores) you have in the orchard is a big factor for your risk of infection!

Risk of gray mold

Preharvest fungicide	Preharvest rain	Orchard condition		
		Good	Average	Poor
Yes	No	Low	Low	Moderate
Yes	Yes	Low	Moderate	High
No	No	Low	Moderate	High
No	Yes	Moderate	High	Extreme

Spotts et al.

Preharvest management Overhead Irrigation/ Cooling

- Adds moisture and spreads spores
- Consider the risks
- Plan your sprays around it
- Consider netting
- Cycle cooling to avoid long wet periods

Preharvest Chemical control

1. What are the most effective preharvest fungicides?
2. How many times should I spray in the orchard?
3. What the best time to apply preharvest sprays

Fungicides

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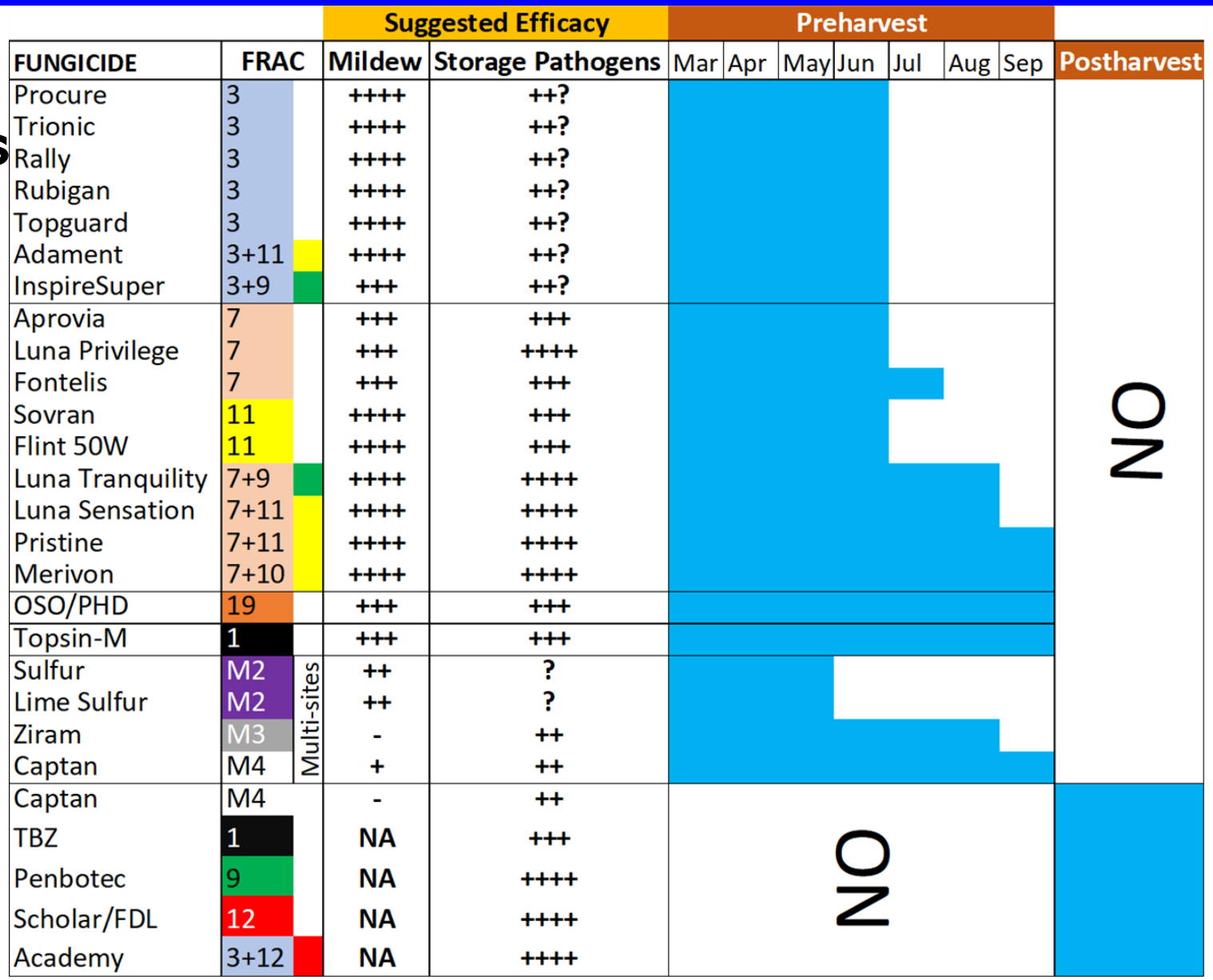
- 22 Preharvest fungicides
  - 19 single-site
  - 3 multi-site (Captan, Ziram, Sulfur)
- 5 Postharvest fungicides
  - 4 single-site
  - 1 multi-site (Captan)



Preharvest fungicides:

Past & current approach?

Mildew Sprays

Rots

Preharvest fungicides:

Which way to go?

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- Most common approach
  - Bins are set in orchards 2-4 weeks before harvest
  - Limit access to orchards for sprays
  - One Spray: 30-0 Days preharvest ?

Module I-Part 2

- Pathogens present in orchards
- Infections may occur anytime between bloom & harvest
- Fruit more susceptible closer to harvest

Is there an optimal spray number and better time(s) for applications?

Key timings of pathogen infections in the orchard

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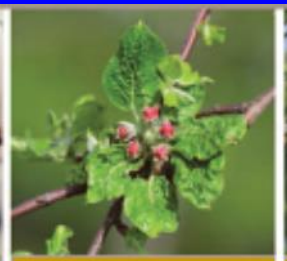
Bud burst


Mouse ear


Pink bud


Petal fall


Fruit set


Fruitlet stage


Fruit filling


Harvest


Postharvest

***Podosphaera leucotricha* (Mildew)**

***Erwinia amylovora* (Fire blight)**

***Alternaria alternata* (Alternaria rot)**

***Botrytis cinerea* (Gray mold)**

***Neofabraea spp* (Bull's eye rot)**

***Phacidiopycnis spp.* (Speck rot)**

Sphaeropsis pyriputrescens

Lambertella c-maris? (Yellow R)

***Penicillium* (Blue M)**

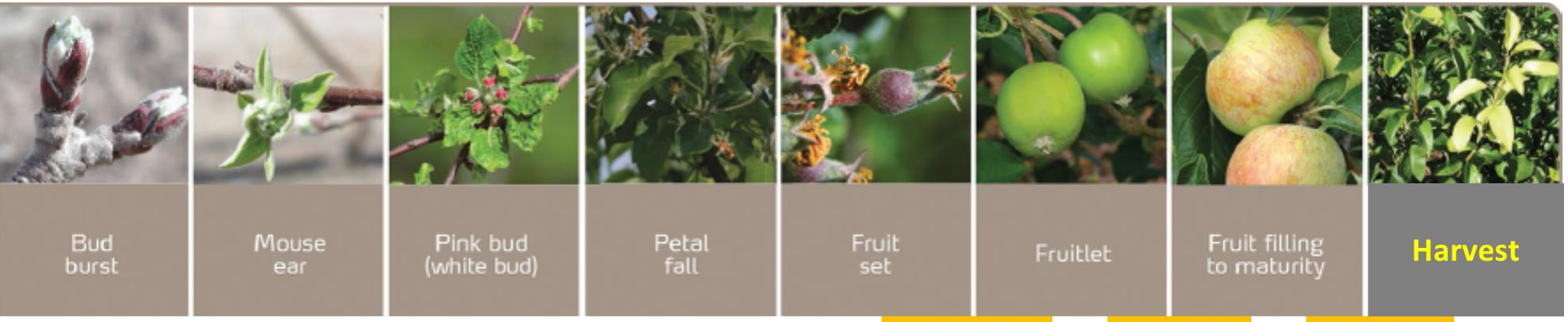
Mucor piriformis

Preharvest fungicides:

Number and timing of applications

Bloom-Petal fall (PF) | F. set-Fruitlet | PF + 45 d | 14-0 DPH

Option A
4 preharvest sprays



F. set-Fruitlet | PF + 45 d | 14-0 DPH

Option B
3 preharvest sprays

Preharvest fungicides:

Which fungicide to spray? - Example

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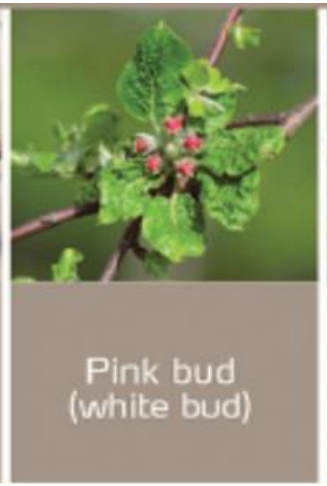

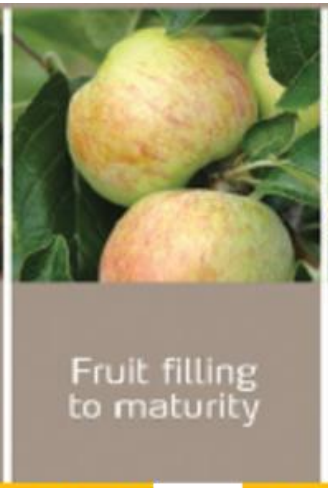

Bloom-Petal fall (PF)

FRAC 7+11

or

FRAC 19

F. set-Fruitlet

FRAC 1

or

FRAC 3

PF + 45 d

FRAC 9+3

14-0 DPH

FRAC 7+11

or

FRAC 1

Spray different fungicides at different timings in following season

Factors that might affect efficacy of preharvest fungicides

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- Rain: Late cultivars
- Overhead irrigation
- Rate: low vs. high label rate
  - Use higher label rate: better control
- Fungicide resistance: Module 3

Harvest at commercial maturity: Over-mature fruit are more susceptible to decays

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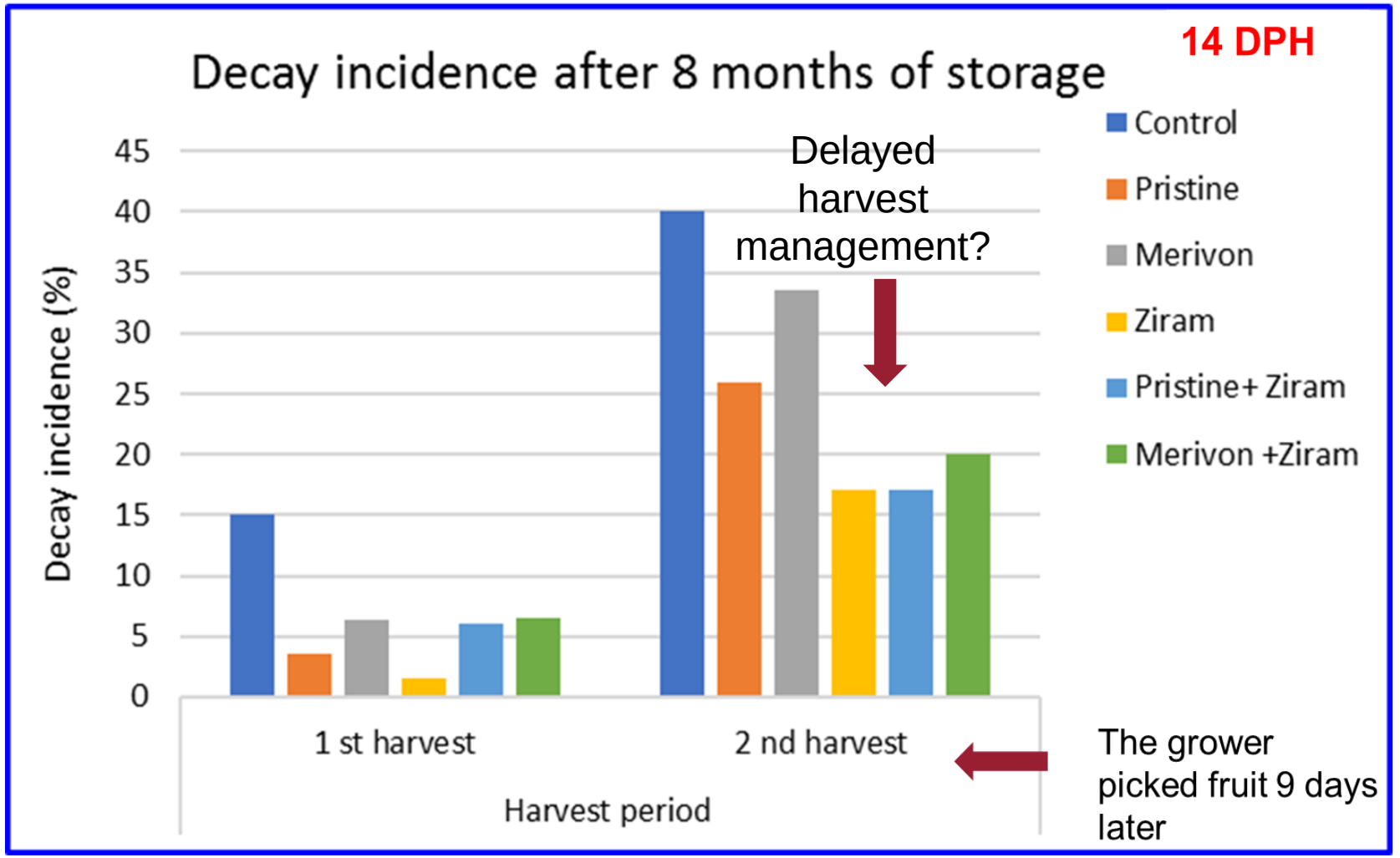

Postharvest Management

1. Do fruit infections stop after harvest ?
2. How to better prepare for the storage season?
3. Which fungicide works better and how to apply it?

Postharvest Management

1. Do fruit infections stop after harvest ?
   Module I-Part 2

   - Infections by field pathogens stop but decay may start developing in storage.

   - Infections by blue mold and Mucor rot start at harvest and continue during storage and packing.

Why is postharvest sanitation important to fight decays?

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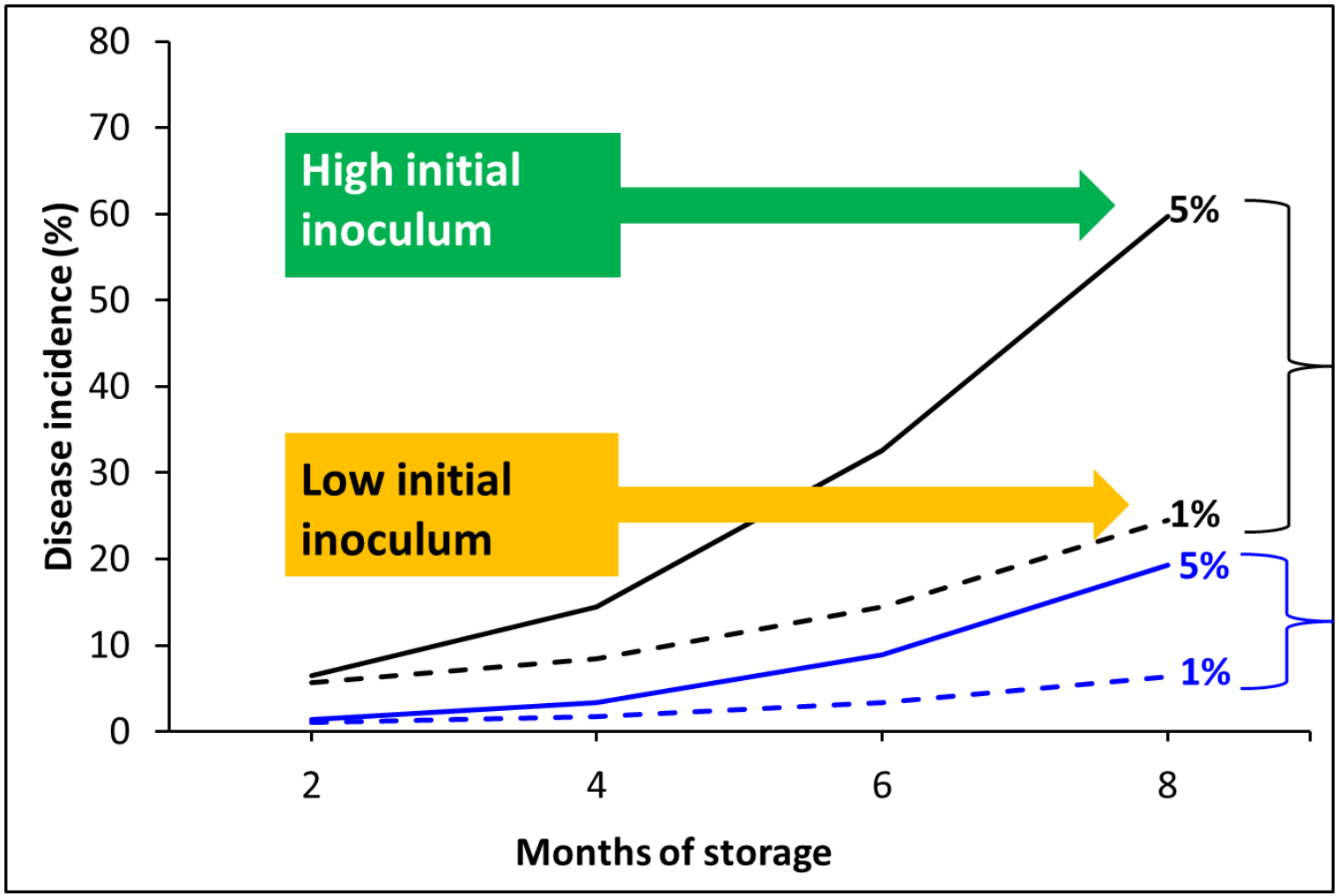
Inoculum size **at beginning of storage** is critical



Cultivar with high susceptibility: example Honeycrisp, Gala, Fuji

Cultivar with **lower** susceptibility: ex. Red Delicious

Dutot et al. 2013.

Preparation for the storage season: Cleaning and Sanitation

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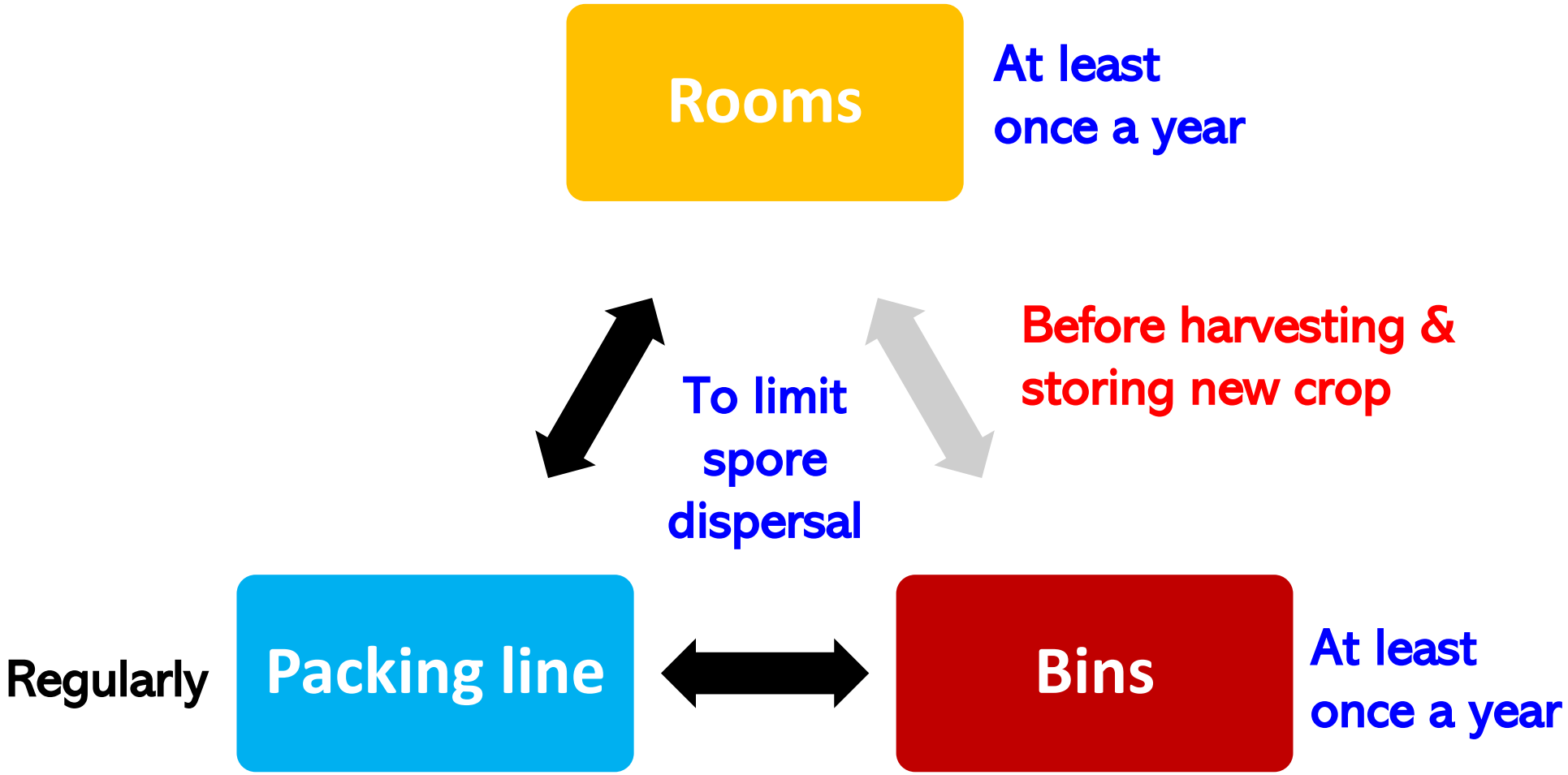

Preparation for the storage season:

Cleaning and Sanitation

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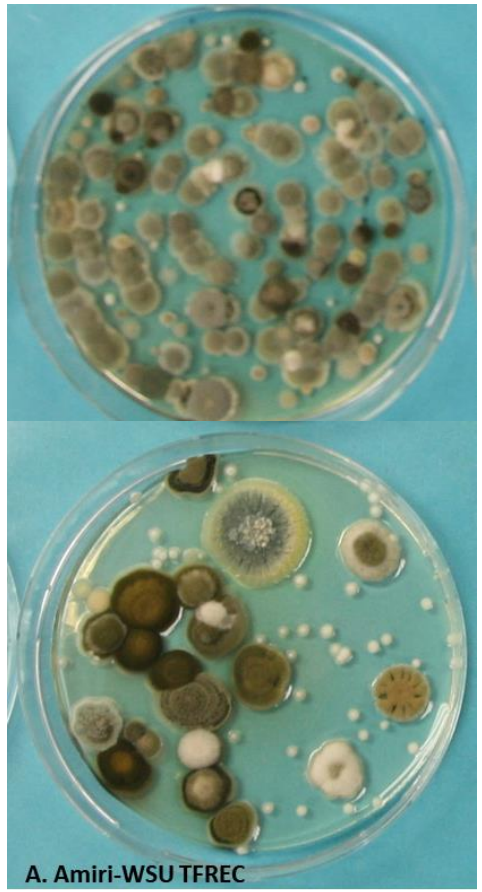
Major pathogens of <u>concern</u>: *Penicillium* (blue mold), Mucor & *Cladosporium* (secondary)

Others: Spores of *Neofabraea* (bull's eye rot) and *Botrytis* (gray mold) found on bins

Rotten fruit touching bin sides

Abundant spores released to air and walls

Fully decayed fruit in bins: Cleaning <u>a must</u>



Airborne spores trapped from airs of storage rooms

Preparation for the storage season:

Cleaning and Sanitation Bins

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Photos are subject to copyright

- **Wash bins after dump-tank**
- **Pressurized hot water**
- **Ozone fog?**
- **Hot summer may kill spores**
- **Brush underside bins before stacking or immersing in water**

Preparation for the storage season:

Cleaning and Sanitation Rooms

Photos are subject to copyright

- Spores move: Remove decayed fruit inside & outside of rooms
- Wash walls and floors: detergent & sanitizer
- Gas/Fog: Ozone or PAA?
- Clean closer to harvest: avoid re-contaminations

Preparation for the storage season: Cleaning and Sanitation

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Sanitizer	Trade name[1]	Effective dose[2]	Efficacy against *Penicillium*[3]	
			Exposure time	Spore kill%
Quaternary Ammonium Compounds	Multiple	2-8 ml/L	3-10 min	• 87-97
Chlorine compounds • Na^+ or ca^{++} hypochlorite[4] • Chlorine dioxide	Multiple	• 50 ppm @ 75°F • 3.5 mg/L	• 3-5 min • 10-20 min	• 70-80 • 70
Peroxides -Hydrogen -Peroxyacetic	-Jet-Ag -StorOx -StorOx 2.0	• See Labels		• 0-80
Ozone[5] -Liquid -Gas or fog	Multiple	0.5-1.2 ppm	• 2-5 min • 2 hr -48hr	• 40-70 • 60-90

pH will impact

Closed doors=foam

Pay attention to pH (read labels)

Practices to be aware of

Pre-sizing: Apples

1. Storing wet fruit in cold storage for months
2. Provides additional moisture to fungi
3. Possible recontaminations in flume water
4. Apply a fungicide on the line?

Practices to be aware of

Pre-packed pears

Pre-packing: Pears

1. Fruit sized and treated with a fungicides
2. Possible recontaminations in flume water
3. Stored in card-boxes and foils that may create generate moisture
4. Repack if decay is >2%

Postharvest fungicides

1. Which fungicide works better ?

2. Is there a better method to apply fungicides?

Known efficacy* of current postharvest fungicides

Decay	Scholar (FDL)	Penbotec (PYR)	TBZ	Academy (FDL + DIF)
Blue mold	Excellent	Very good	Good	Excellent
Gray mold	Very good	Excellent	Good	Very good
Sphaeropsis rot	Excellent	Very good	Fair	Excellent
Phacidiopycnis/ speck rot	Excellent	Very good	Fair	Excellent
Yellow rot	Excellent	Good	Fair	Excellent
Bull's-eye rot	Low	Good	Excellent	Fair
Mucor rot	None	None	None	Low
Application method	Drench & Fog	Drench & Fog	Drench & Fog	Drench

* Efficacy in absence of fungicide resistant populations of the fungus (Module 3)

Additional postharvest fungicides

- **Judge** (a.i. Fenhexamid)

JUDGE™ 50 WDG Fungicide
For Use on Post-harvest Pear, Asian Pears, Pomegranate, Plums and Prunes, Fresh,

GROUP 17 FUNGICIDE

  - For pears only
  - Very good for gray mold:
  - Drench or packing line only
  - 1 -1.5 lbs/200,000 lbs fruit

Rotate W/others on packing line?

- **Captec 4L** (Captan, FRAC M04)
  - Fair efficacy: Gray mold, bull's eye rot
  - Short storage?
  - Drench or packing line only
  - 0.75-1.0 Qts/100 gal

Captec® 4L
CAPTAN FLOWABLE FUNGICIDE

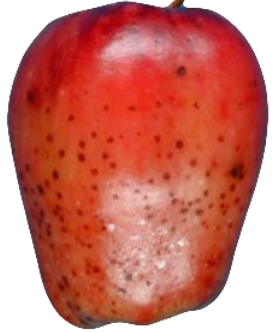
Application methods of postharvest fungicides: Bottom-line

Good Orchard management + Poor warehouse management — Dry

Poor Orchard management + Good warehouse management — Wet

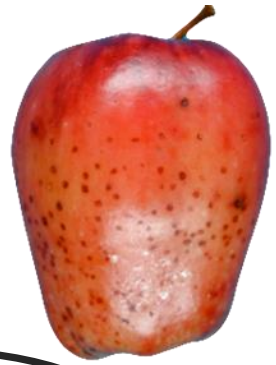
Good orchard management + Good warehouse management — **Either** — Cost?

Preharvest Sanitation	Good/timely prehavest spray	Postharvest sanitation	Expected storage duration (months)		
			≤ 3	4-7	>8
Yes	Yes	Yes	None	Dry	Eitheir
Yes	Yes	No	None/Dry	Dry	Dry
Yes	No	Yes	Dry	Wet	Wet
Yes	No	No	Dry	Dry	Dry
No	Yes	Yes	None	Eitheir	Wet
No	Yes	No	Dry	Dry	Dry
No	No	Yes	Dry	Wet	Wet
No	No	No	Dry	Dry	Dry



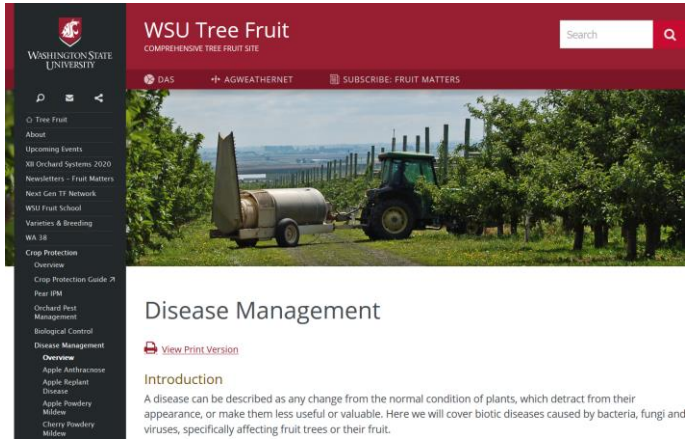
Summary

- Observe preharvest cultural practices
- Apply fungicides from different groups
- Apply fungicides timely
- Observe excellent postharvest sanitation practices
- The postharvest fungicide will help optimize control



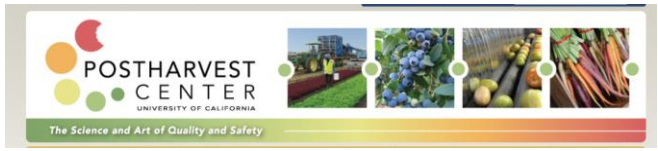
Additional Resources

- Factsheets provided in the packet
- WSU TREE FRUIT: http://treefruit.wsu.edu/



- PNW Plant Disease Management Handbook https://pnwhandbooks.org/plantdisease

- Postharvest Center http://postharvest.ucdavis.edu/



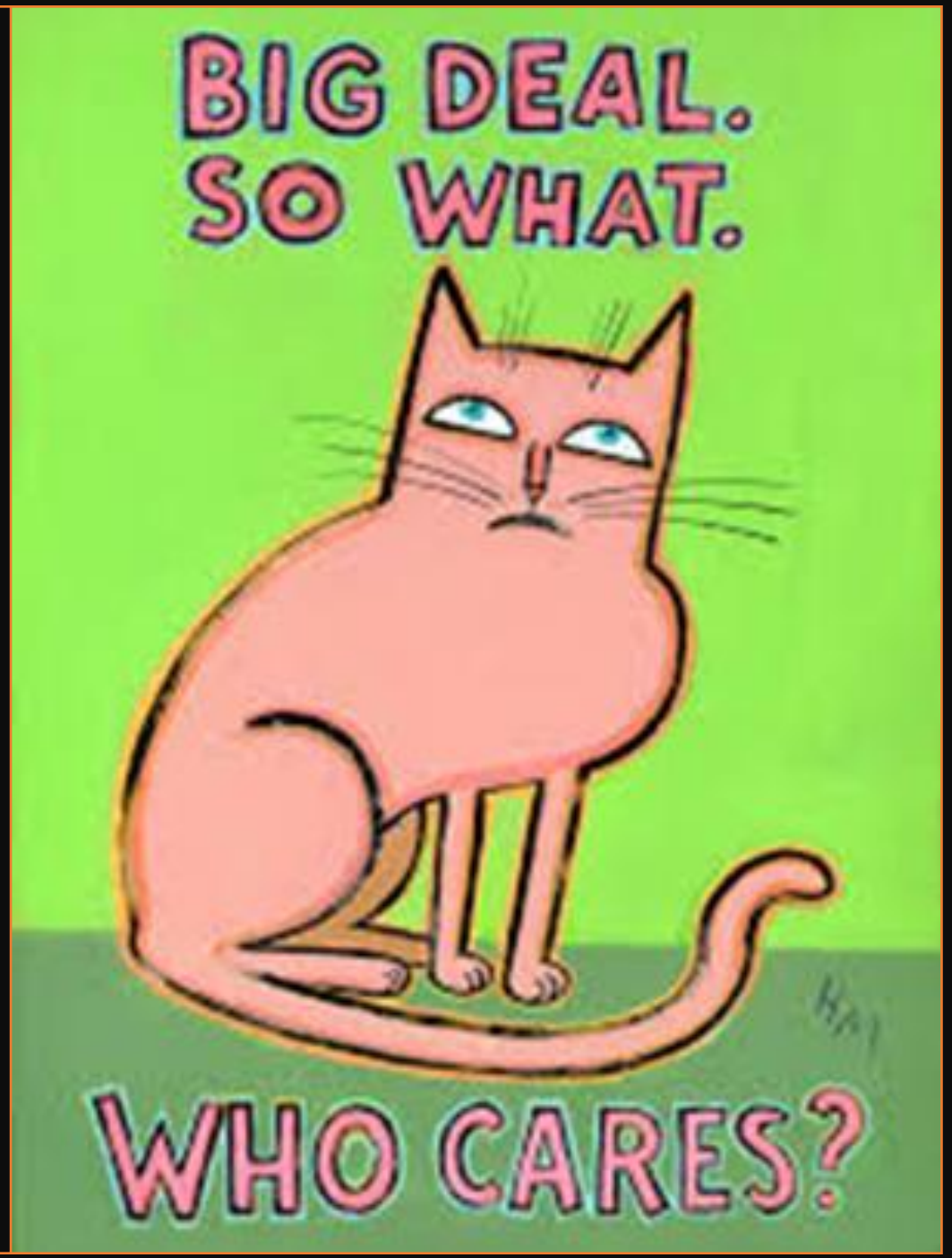
Module III

Fungicide Resistance: Development & Mitigation

Learning Objectives

- Better understand fungicide resistance
- Fungicide resistance occurrence in the PNW
- Reasons behind resistance development
- Conduct risk assessment
- Prevent & Mitigate fungicide resistance

As a grower or a packer, should I really worry about fungicide resistance when I develop my spray program?



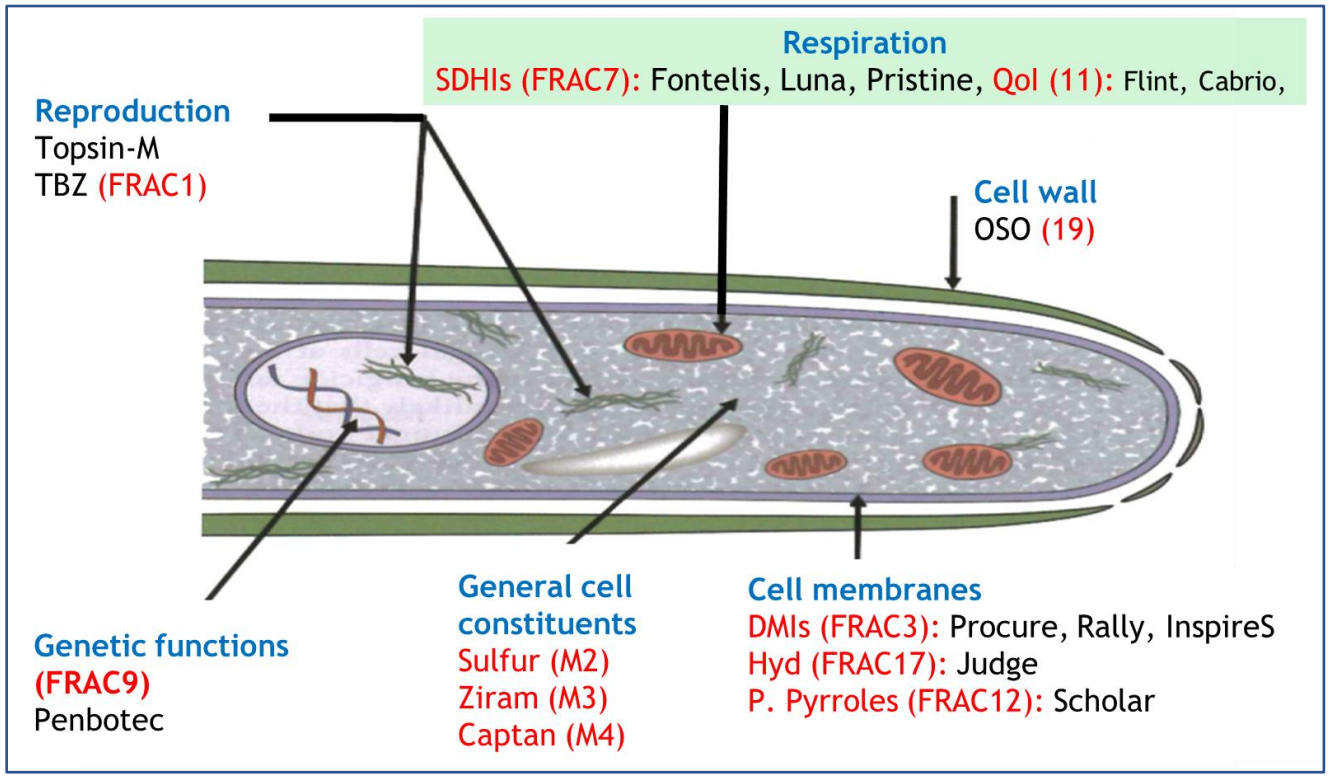
Is fungicide resistance caused by the:

- ❑ Fungicide? ✓
- ❑ Pathogen? ✓

Question

Fungicide resistance can be defined as the evolution (change in genome) of the pathogen population caused by the fungicide selection pressure

Mode of action vs. site of action



Mode of action of fungicides:

Respiration, reproduction, etc

Site of action of fungicides:

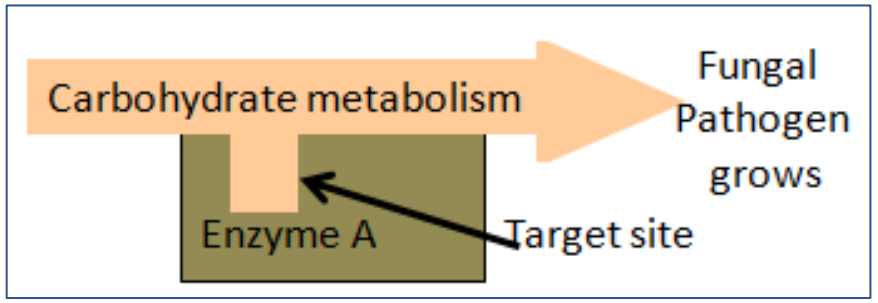
- Multi-sites: Target Several sites
- Single-site: Target One site

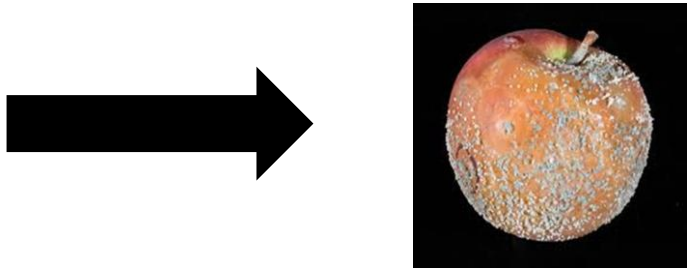
- Example: Pristine and Merivon have the same site of action = potential cross-resistance

- Single-sites are at risk for fungicide resistance

Sensitive fungus

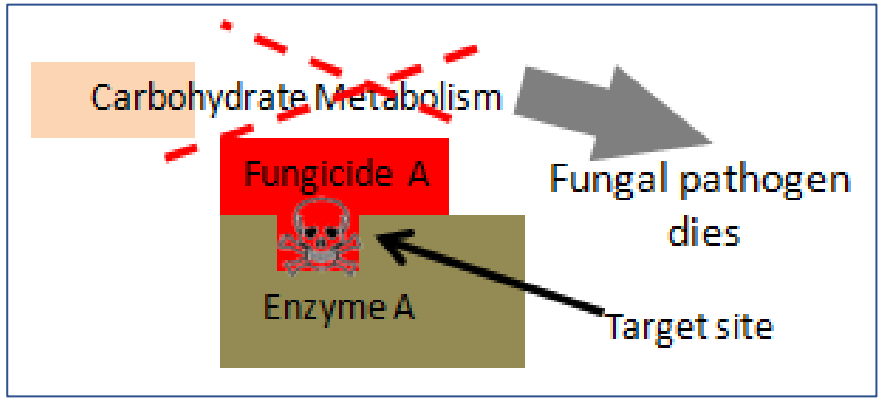
Fungicide not applied

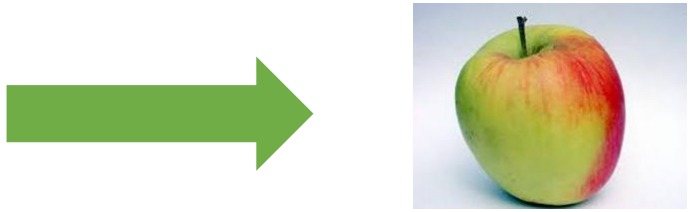




Sensitive fungus

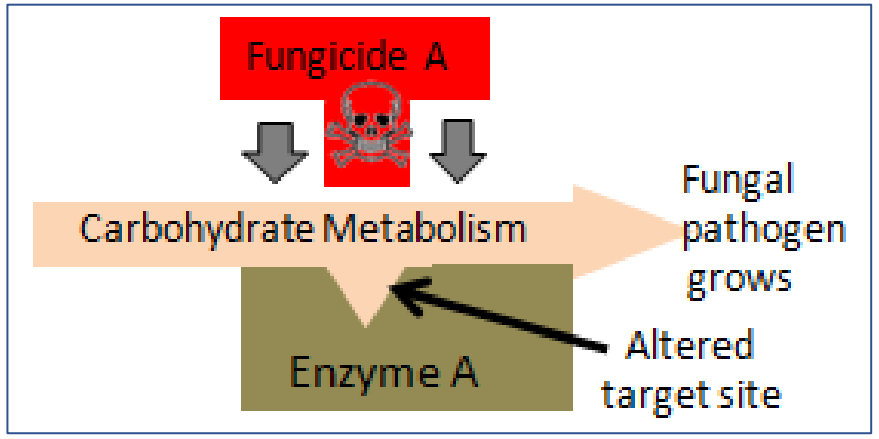
Fungicide applied

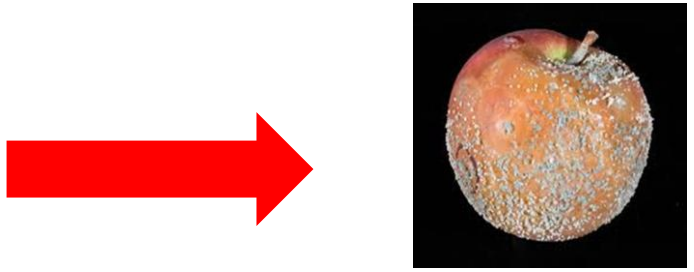




Resistant fungus

Fungicide applied





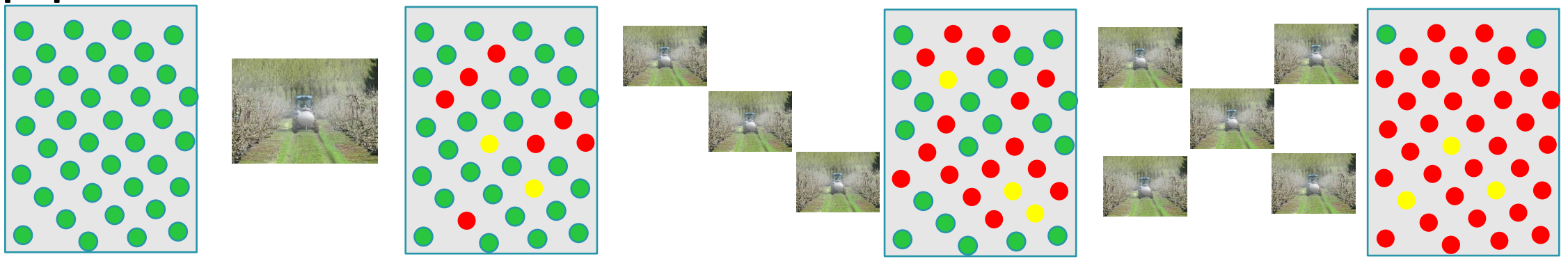
Sensitive Reduced sensitivity Resistant

Initial population

Year 1-3

Year 4-6

Year 7-9



Excellent Control

Good Control

Moderate Control

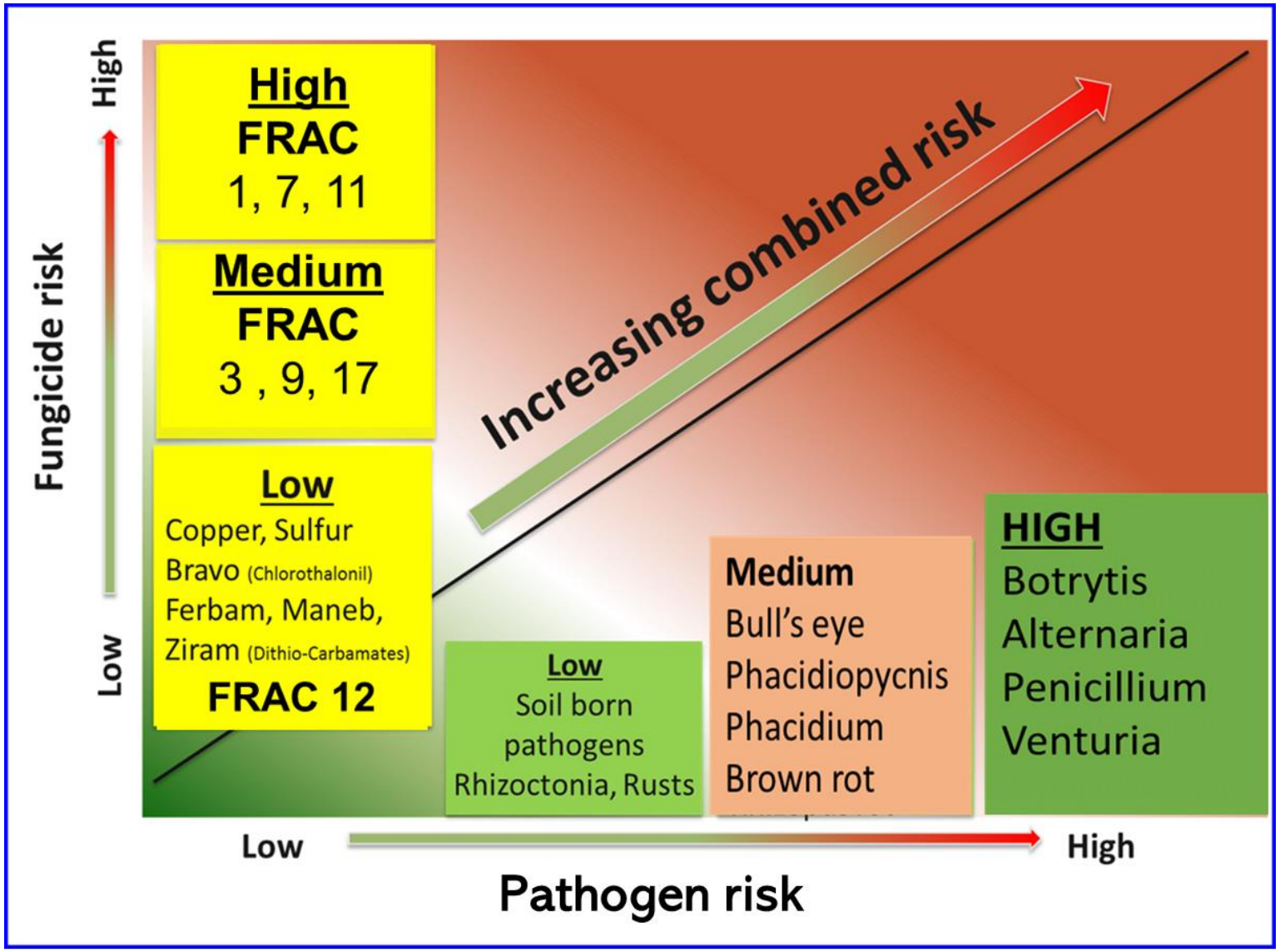
Control Failure

Sensitive → Tolerant → Fully-resistant

Stepwise and progressive selection of resistant populations

Fungicide Resistance is a combined risk

Fungicide
X
Pathogen



Status of fungicide resistance in the PNW

Disease name	*Pathogen name*	Resistance status in the PNW
1. Gray mold	*Botrytis cinerea*	Documented
2. Blue mold	*Penicillium expansum*	Documented
3. Bull's eye rot	*Neofabraea* spp.	Suspected (FRAC1)
4. Alternaria rot	*Alternaria alternata*	Suspected
5. Speck rot	*Phacidiopycnis* spp.	Unknown
6. Sphaeropsis rot	*Sphaeropsis pyriputrescens*	Unknown
7. Yellow rot	*Lambertella corni-maris*	Unknown
8. Mucor rot	*Mucor piriformis*	N/A

Questions

I have resistance to TBZ in my warehouse:

- ❑ No worry; I still have Scholar and Penbotec
- ❑ I need to know more before I start worrying? ✓

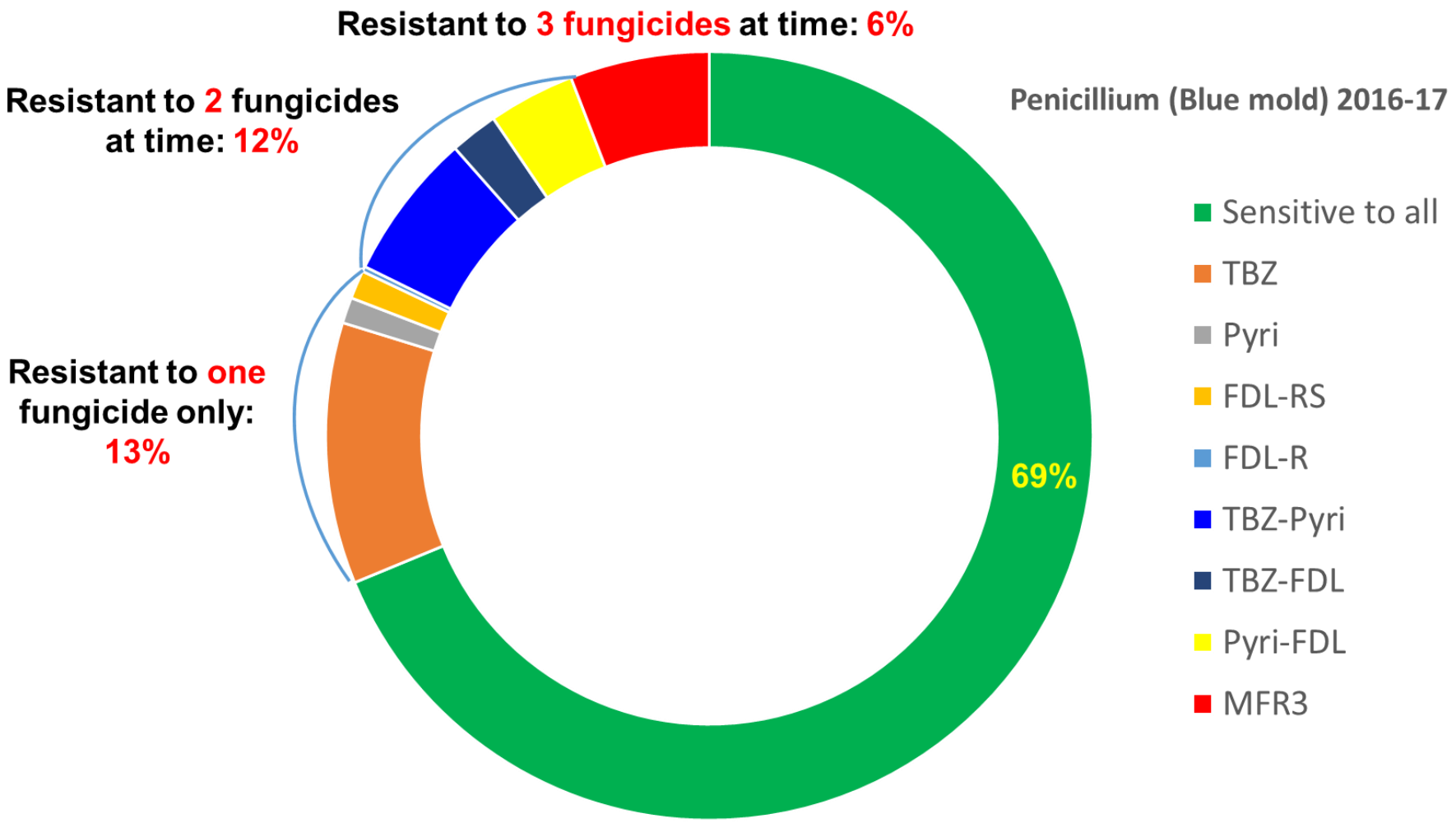
What else do I have to consider?

- ❑ Resistance to other fungicides ✓
- ❑ Multiple*-resistance to other fungicides? ✓

* Multiple-resistance = strains resistant to more than 1 fungicide at a time

Example: Blue *mold-Penicillium* resistance 2016-17- Washington State

2,000 strains screened



Similar situation for gray mold

Impact

How is this knowledge beneficial for decay control?

- Most growers and packers in PNW have low to moderate fungicide resistance risk
- Most trains are either sensitive to all fungicides or resistant to one fungicide at time
- Opens room for rotation of fungicides from different FRACs
- **BUT** 20-30% of growers/packers in PNW are at higher risks: need to implement drastic changes

Source(s) and path of resistant populations

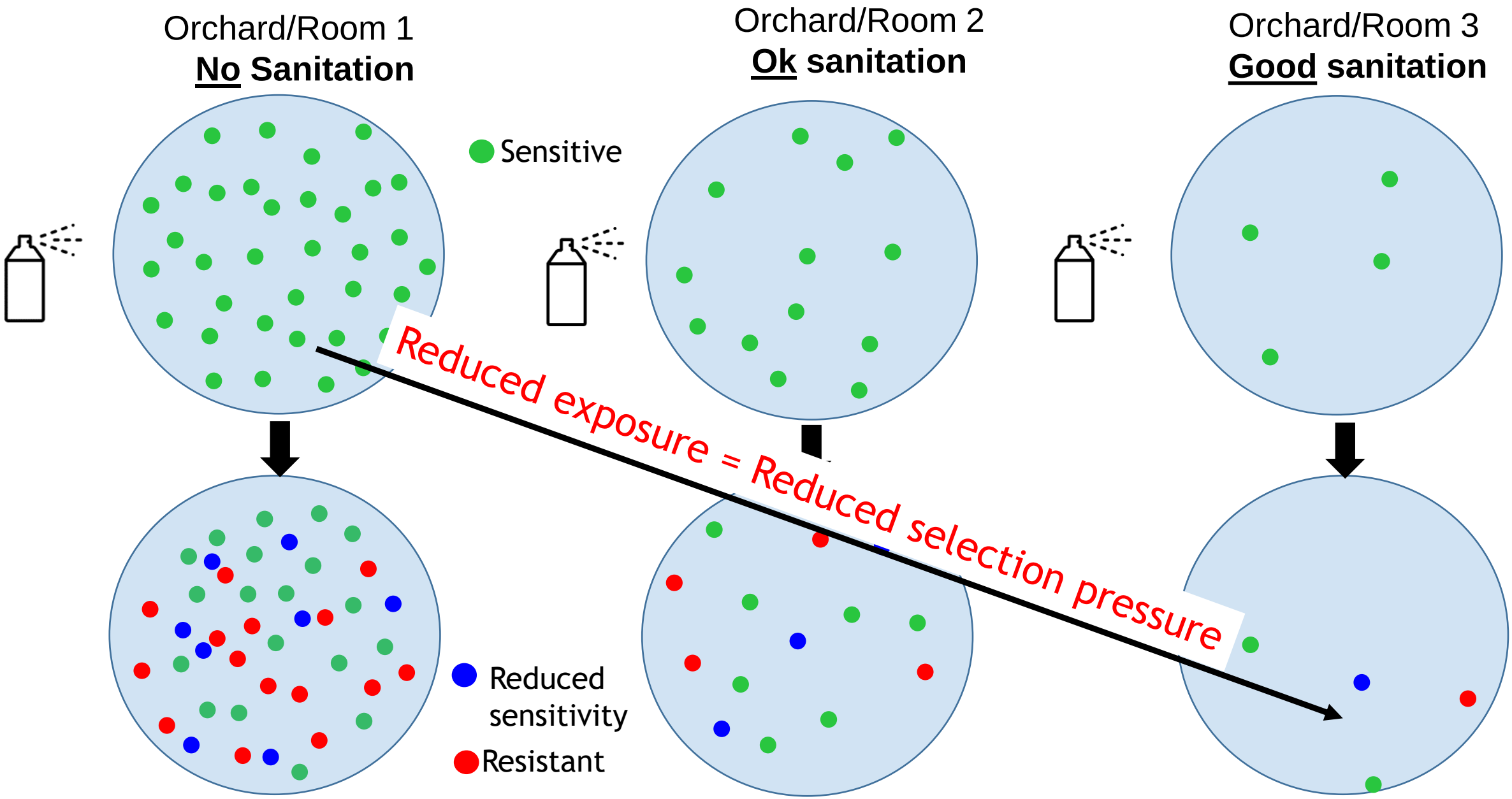
We <u>may not spray frequently</u> but the **exposure time** in pome fruit is <u>longer than in any other system</u>

Fungicide Resistance Mitigation

Proactive Fungicide Resistance Avoidance

- It takes on average 10 years to develop and register a fungicide
- More challenging to register new postharvest fungicides
- Best strategies should start upon registration to extend fungicide lifespan

Cultural Practices: Sanitation to lower inoculum load: HUGE impact



Gray mold: *Botrytis* Preharvest sanitation is key

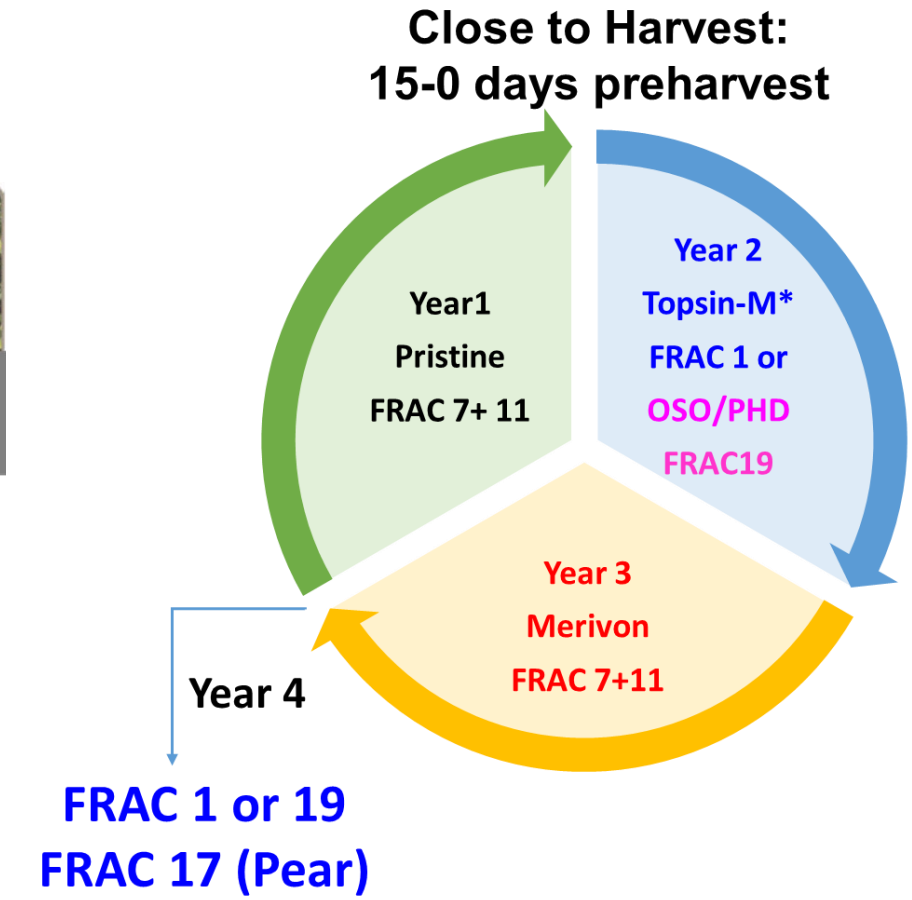
Modules 1 & 2

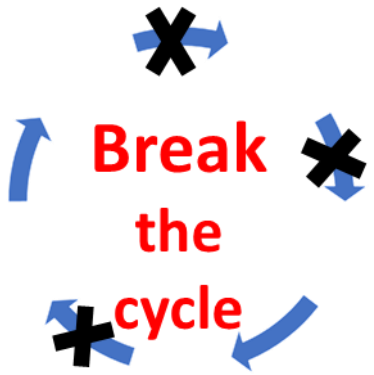
- *Botrytis* is a latent (dormant) pathogen: the cleaner the fruit at harvest the lower the gray mold risk in storage
- Remove all potential sources of inoculum: Mummies, litter, weeds
- Avoid excess of overhead cooling/irrigation
- Spray timely: 7 days preharvest may not eliminate latent infections (Module 2)

Rotation of fungicides in the Orchard

Module 2

Bloom-Petal fall (PF)	F. set-Fruitlet	PF + 45 d	14-0 DPH
FRAC 7+11	FRAC 1	FRAC 9+3	FRAC 7+11
FRAC 19	FRAC 3		FRAC 1





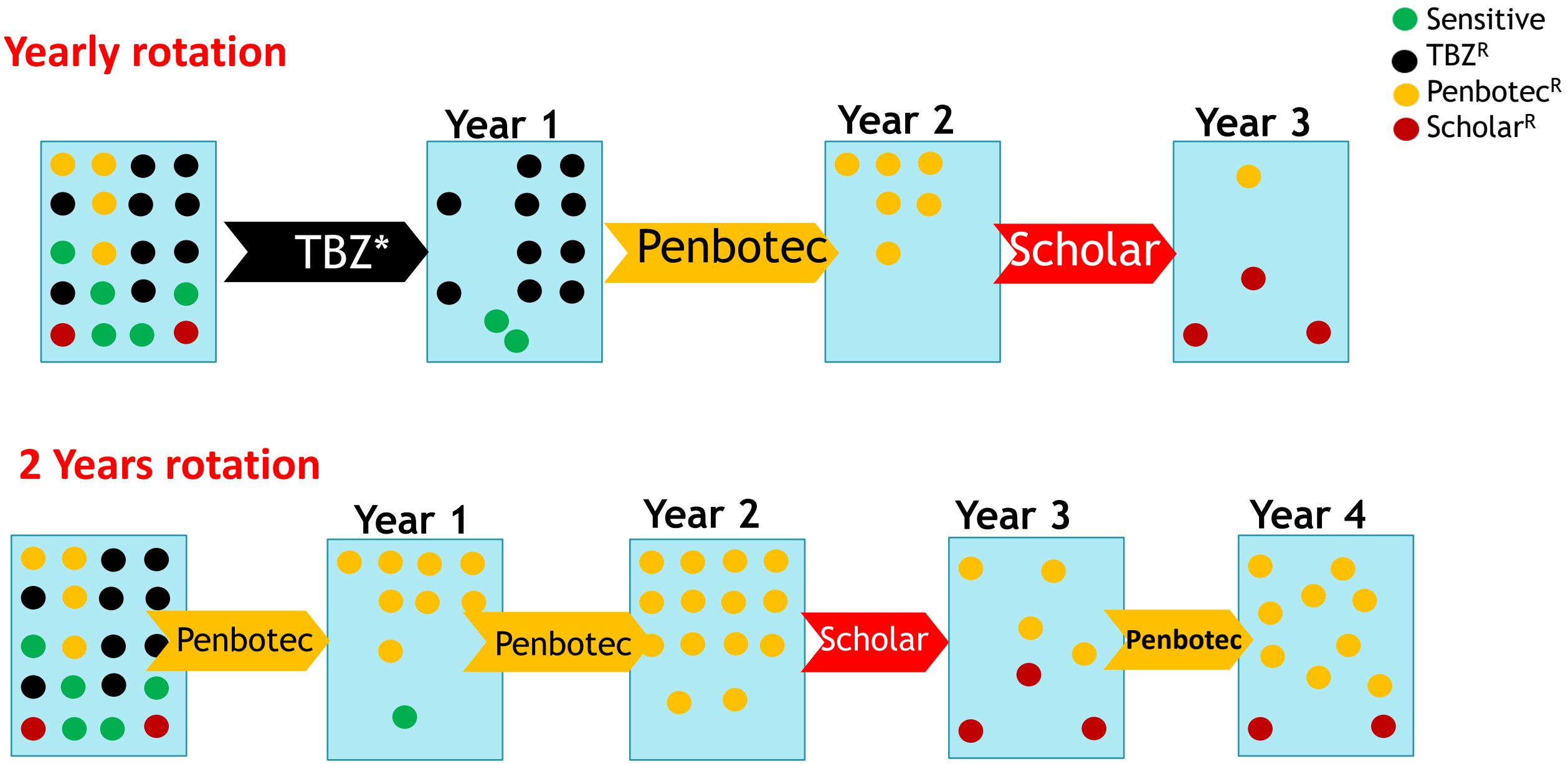
The case of FRAC 7 fungicides and *Botrytis:* Cross-Resistance

If Resistant to ↓	Luna	Fontelis	Aprovia	Merivon	Pristine
Luna-R	R	R	R	R	R
Fontelis-R	S	R	R	R	R
Aprovia-R	S	R	R	R	R
Merivon-R	S	R	R	R	R
Pristine-R	S	S/R*	S/R	S/R	R

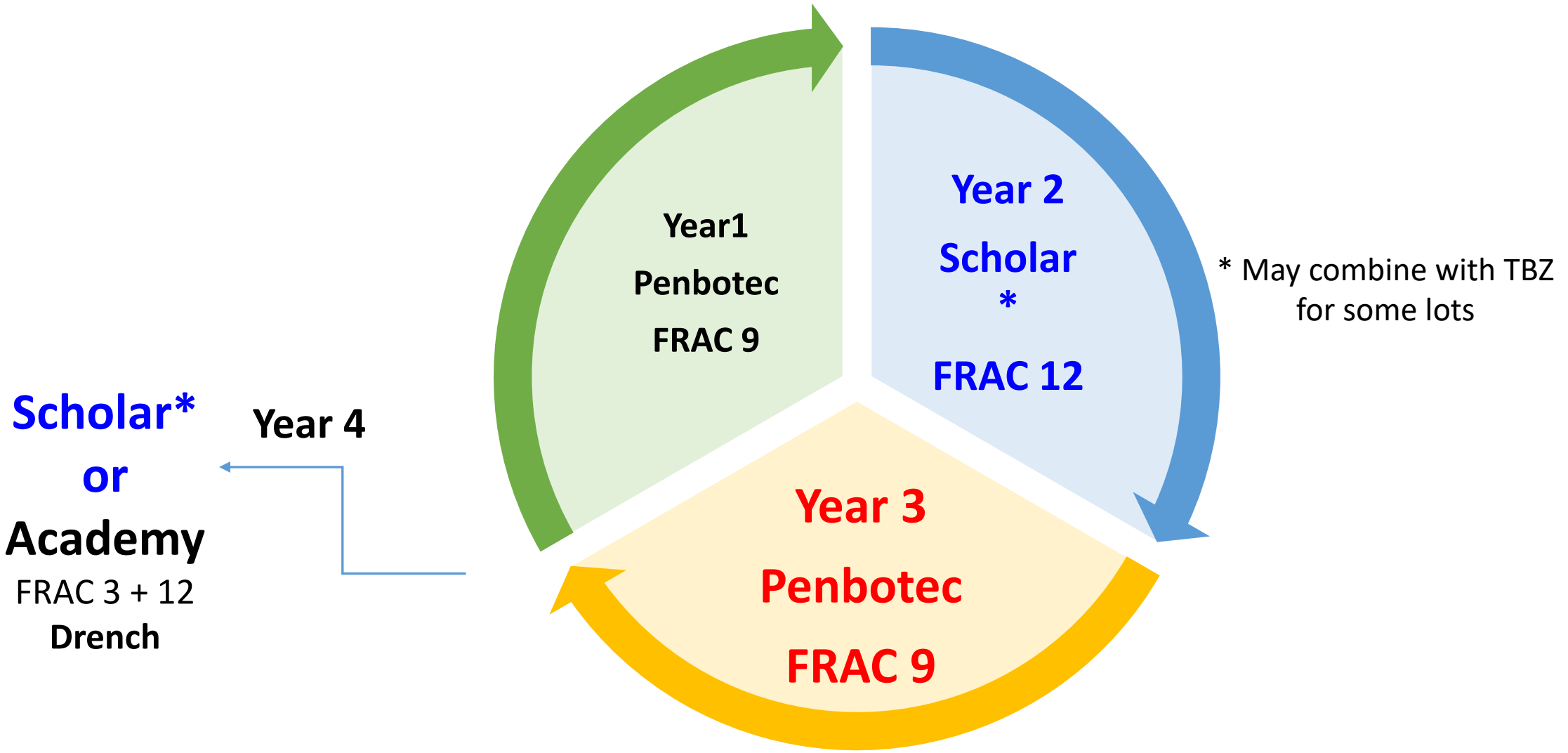
*** Some mutations confer resistance, others not**

If Luna products are over-sprayed early season, they may select for resistant populations that will not be controlled by any other FRAC 7

Rotation (Alternation) of fungicides: Pre- and Postharvest



Rotation of postharvest fungicides



Label rate

High vs. low

Is there a real risk?

- **Low label rate:**
  - Fungus may adapt
  - Develop tolerance or reduced sensitivity
- **Use higher label rate:**
  - Better control
  - Reduces inoculum (sanitation)
- **Postharvest:**
  - Dry application may result in variable residue levels within the room
  - Effect unknown

Summary

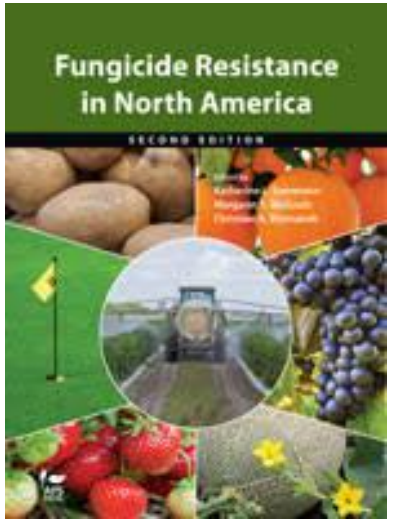
- Fungicide resistance has developed/emerged in the PNW
- Overall Resistance frequencies are low to moderate: Mitigation options available
- 20-30% growers/packers need to implement drastic changes to avoid total control failure
- Be proactive, act upon registration, and consider fungicides as YOURS
- Sanitation: lower exposure = lower risk
- Contact us if you need help to profile your locations

Additional Resources

- Factsheets provided in the packet: Resistance Management

- Fungicide resistance in crop pathogens: how it can be managed? https://www.frac.info/docs/default-source/publications/monographs/monograph-1.pdf?sfvrsn=8&sfvrsn=8

- Fungicide Resistance in North America, 2nd edition (2019)



- Fungicide Resistance Action Committee (FRAC) https://www.frac.info/

Contact

For any additional question, please contact:

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