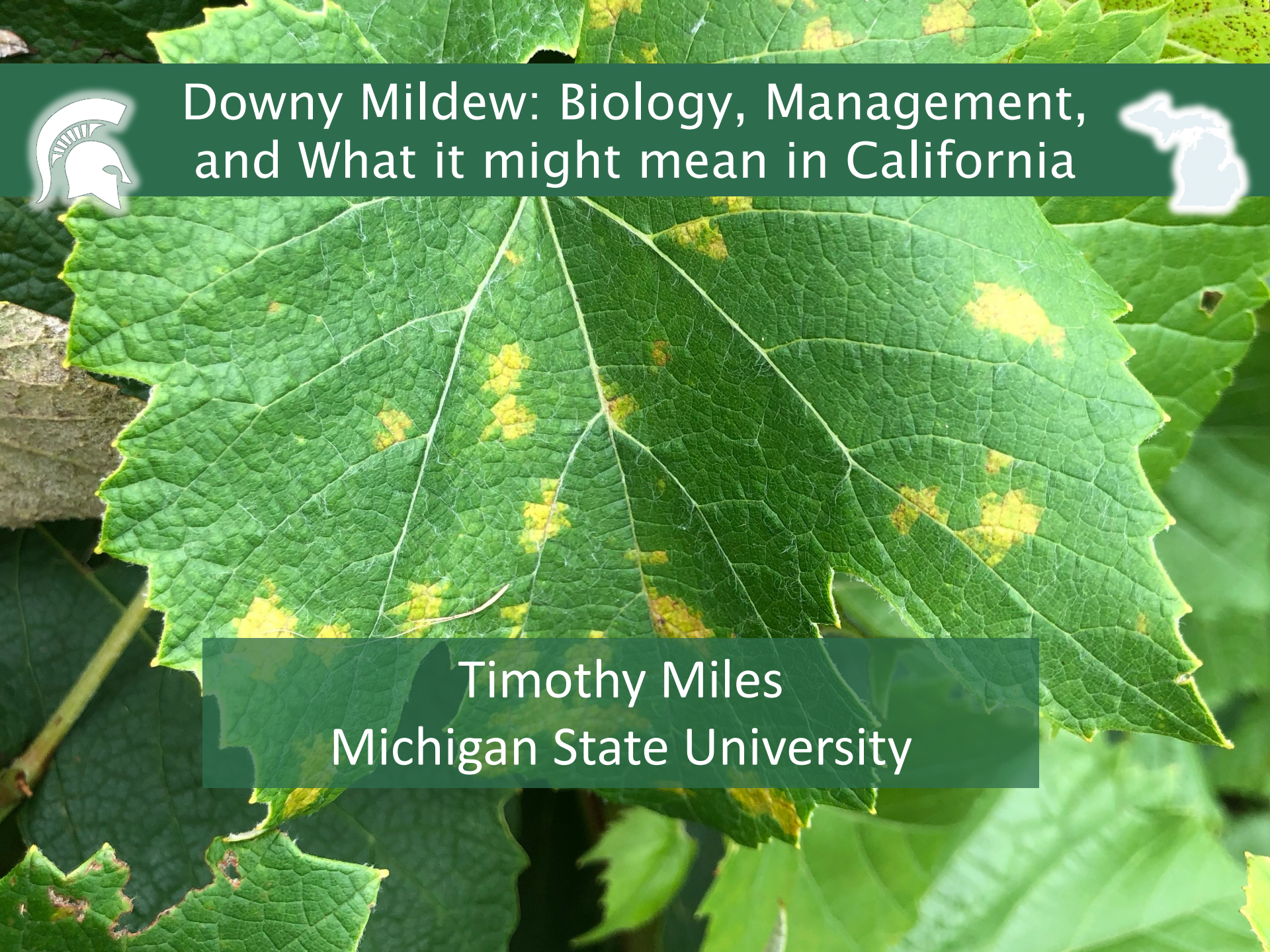


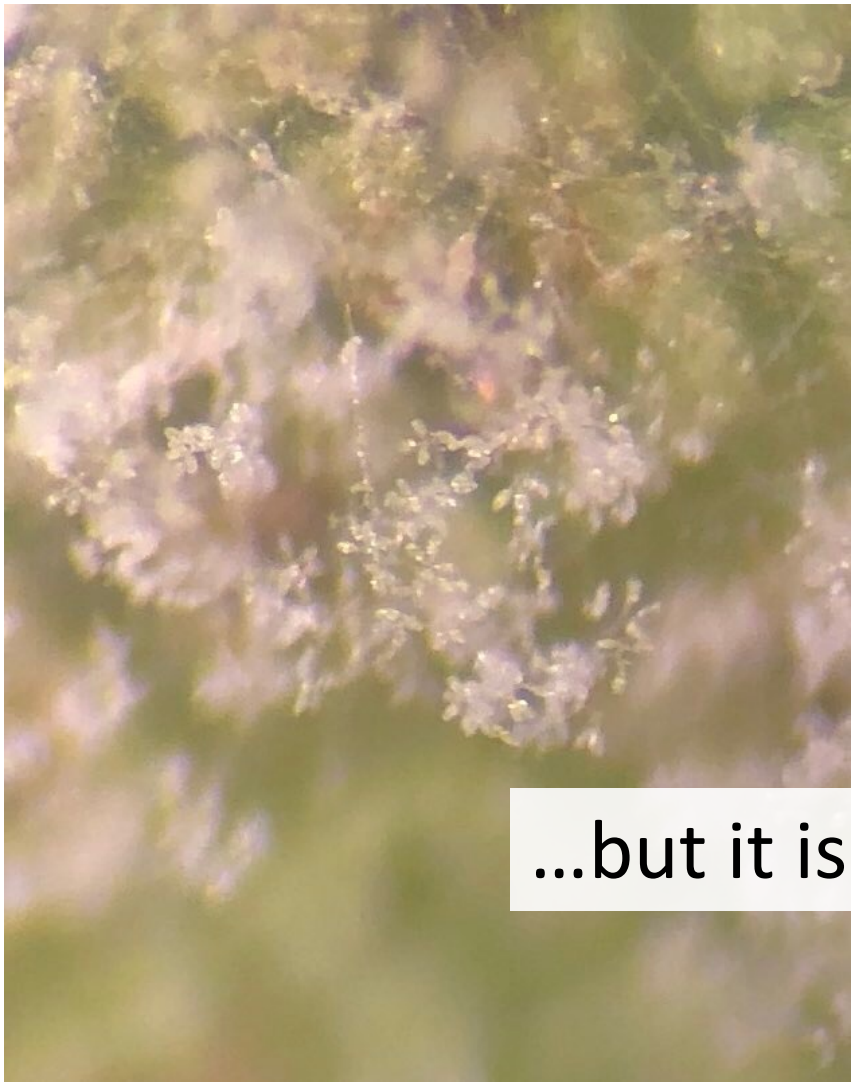
Downy Mildew: Biology, Management, and What it might mean in California

Timothy Miles
Michigan State University

Downy mildew is named for its fuzz like appearance on leaves



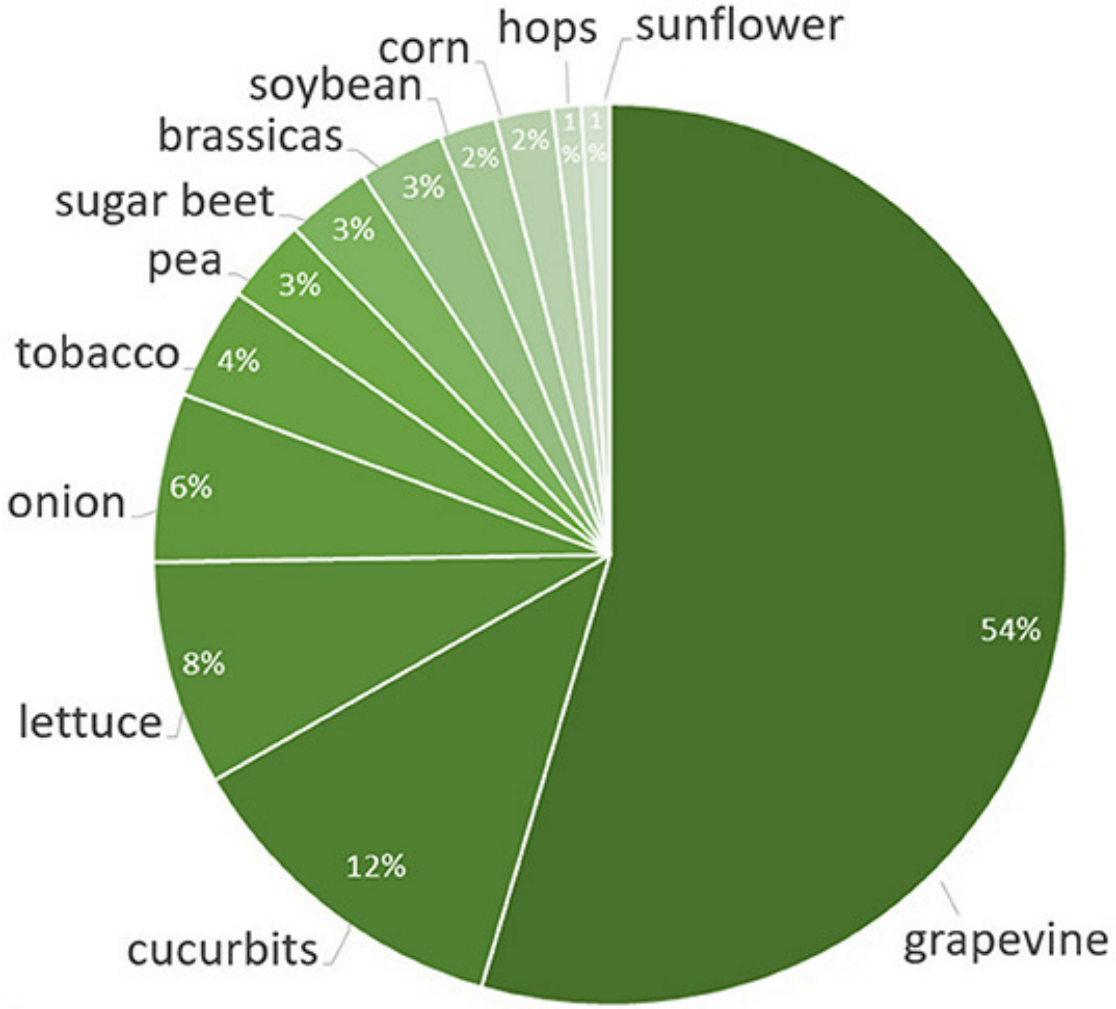
This fuzz is composed of sporangia (spore like structures)





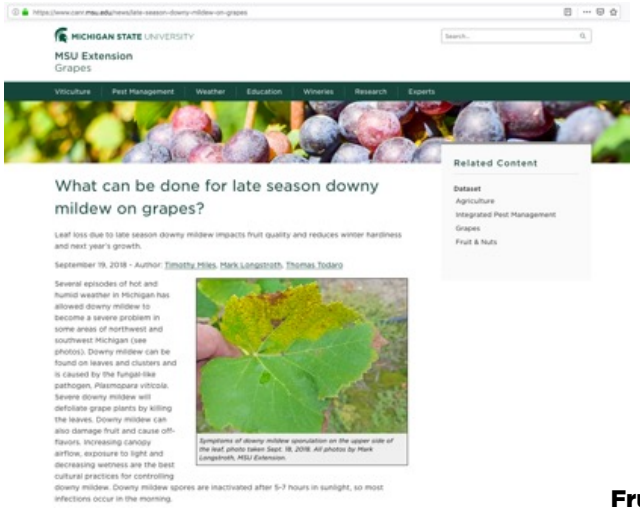
…but it is **NOT** a ***true*** fungus!

The most common crop damaged by downy mildew



Koledenkova et al., 2022

Before we get into DM, there are lots of resources out there…


MICHIGAN STATE UNIVERSITY
MSU Extension
Grapes

Viticulture | Pest Management | Weather | Education | Wineries | Research | Experts

What can be done for late season downy mildew on grapes?

Leaf loss due to late season downy mildew impacts fruit quality and reduces winter hardiness and next year's growth.

September 19, 2018 - Author: Timothy Miles, Mark Longstroth, Thomas Todaro

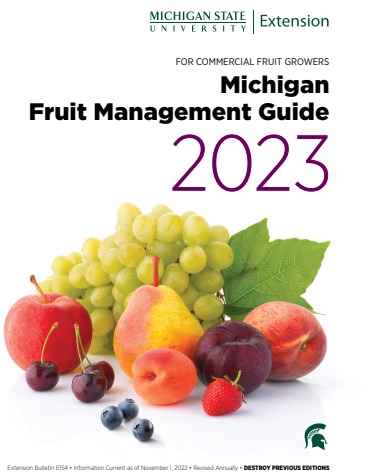
Several episodes of hot and humid weather in Michigan has allowed downy mildew to become a severe problem in some areas of northwest and southwest Michigan (see photos). Downy mildew can be found on leaves and clusters and is caused by the fungal-like pathogen, *Plasmopara viticola*. Severe downy mildew will defoliate grape plants by killing the leaves. Downy mildew can also damage fruit and cause off-flavors. Increasing canopy airflow, exposure to light and decreasing wetness are the best cultural practices for controlling downy mildew. Downy mildew spores are inactivated after 5-7 hours in sunlight, so most infections occur in the morning.

Symptoms of downy mildew sporulation on the upper side of the leaf, photo taken Sept. 18, 2018. All photos by Mark Longstroth, MSU Extension.

Related Content

Dataset
Agriculture
Integrated Pest Management
Grapes
Fruit & Nuts

https://www.canr.msu.edu/grapes/


MICHIGAN STATE UNIVERSITY | Extension

FOR COMMERCIAL FRUIT GROWERS

Michigan Fruit Management Guide

2023

Extension Bulletin E154 • Information Current as of November 1, 2022 • Revised Annually • **DESTROY PREVIOUS EDITIONS**


MICHIGAN
Grape facts
MICHIGAN STATE UNIVERSITY | Extension

Managing grapevine downy mildew

Downy mildew can cause serious yield loss from fruit infections and damage overall vine health, but there are a variety of tools to protect grapes.

By Nancy Sharma[1], Esmaeil Nasrollahiazar[2], Laura Miles[1] and Timothy Miles[1];
[1]Michigan State University Department of Plant, Soil and Microbial Sciences, and MSU Extension[2]

Key messages
- **Resistance** – Choose resistant varieties when possible.
- **Protection** – Protect flowers and leaves with fungicides when the infection risk is high and limit excess irrigation to reduce canopy humidity.
- **Eradication** – Eradicate downy mildew with multisite products if there is significant sporulation as this will reduce overwintering inoculum.

Pathogen
Plasmopara viticola
Kingdom: Chromista
Phylum: Oomycota
Order: Peronosporales

Introduction
Grapevine downy mildew caused by *Plasmopara viticola* is a persistent and destructive disease that poses a significant threat to grape growers. To effectively manage this disease, it is crucial to implement practical strategies and adopt sustainable vineyard practices. By prioritizing sustainability, vineyard owners can protect their grapevines while minimizing the use of fungicides and reducing the risk of resistance development. In this article, we will explore integrated grapevine downy mildew management strategies, encompassing good vineyard practices, biological control and the avoidance of fungicide resistance.

Figure 1. Infected downy mildew leaves and fruit.

Disease signs and symptoms
Downy mildew symptoms can be seen on all green parts of the grapevines. Usually, the symptoms are first observed on the leaves five to 17 days after infection. Foliar symptoms include green to yellow circular spots that appear like oil spots (Figure 1A). Under optimal conditions, several oil spots may develop and merge to cover larger areas of the leaf. Warm and humid nights can lead to white fussy growth (sporangia) on the underside of the infected leaf or other plant parts (Figure 1B, 1C, 1D). Later, the lesions turn brown as the infected tissue dies. Severe infections can lead to premature defoliation (Figure 2). Infected inflorescences can dry up completely and get covered with white sporangia. Young, infected berries change color to dull green or reddish brown and may either die or become discolored. Eventually, these berries can also be covered with white sporangia (Figure 1D). Within three weeks after bloom, berries develop resistance to the pathogen. However, the rachis remains susceptible for several weeks.

1

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MSU vineyard IPM scouting report – Sept. 25, 2019

With grapes being harvested, efficacy of insect and disease control programs can be evaluated for 2019.

Jacquelyn Perkins, Timothy Miles, Rufus Isaacs, Thomas Todaro, Megan Trammel, Mark Longstroth and Michael Reinke - September 25, 2019


2020 PDF
MICHIGAN STATE UNIVERSITY | Extension

A Pocket Guide for Grape IPM Scouting in the North Central and Eastern United States

Produced by Michigan State University Extension

Contents

Sections with clickable index

Insect /mite pests 2
Natural enemies 33
Diseases 42
Physiological/chemical disorders 89
Using this scouting guide 122
Introduction to scouting and sampling 123
Scouting calendar 130
Growth stages 132
Estimating wind speed 134
Credits and acknowledgments 136

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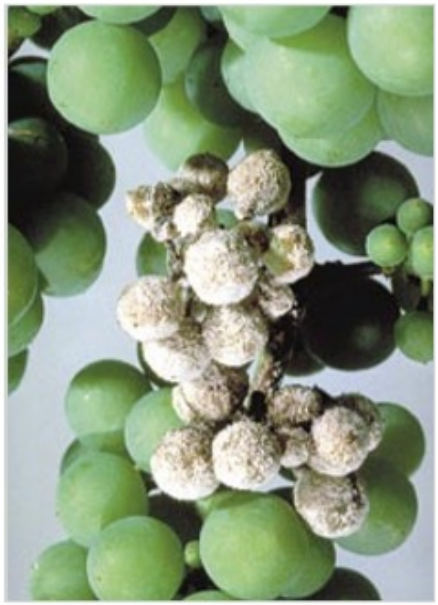
Updated FRAC codes added to fungicide efficacy table

DM symptoms

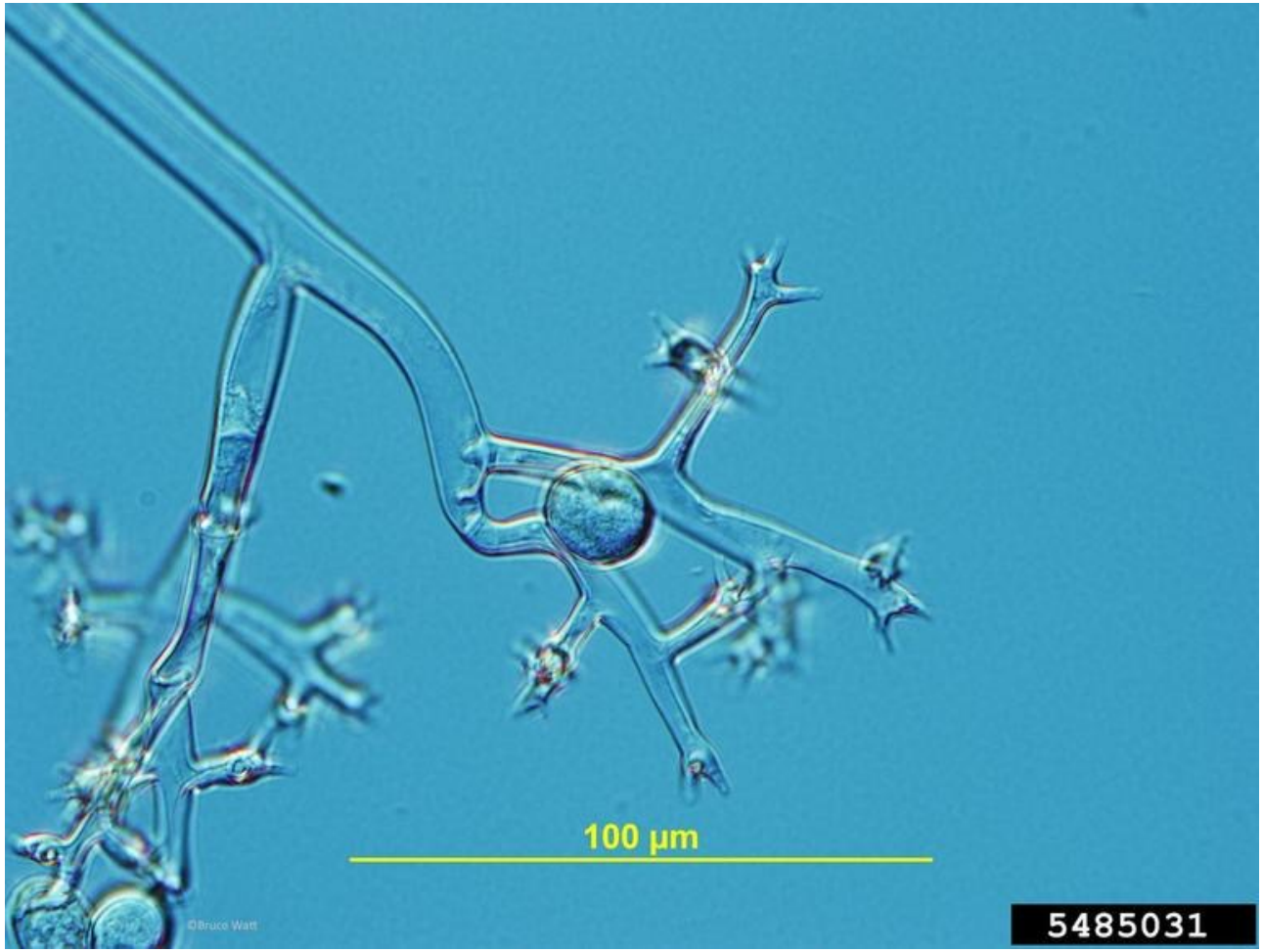
- The pathogen can infect all green tissues of the grapevine and is expressed as yellowish-green lesions on the upper leaf surface at about one to two weeks following infection.
- As lesions expand, the affected areas turn brown and necrotic.
- On lower leaf surface, patches of gray downy growth are usually directly beneath the yellowish-green spots observed on the upper leaf surface.
- Downy cluster infection is expressed as white to gray sporulation on the berries.







Grapevine downy mildew is caused by *Plasmopara viticola* which is an oomycete pathogen



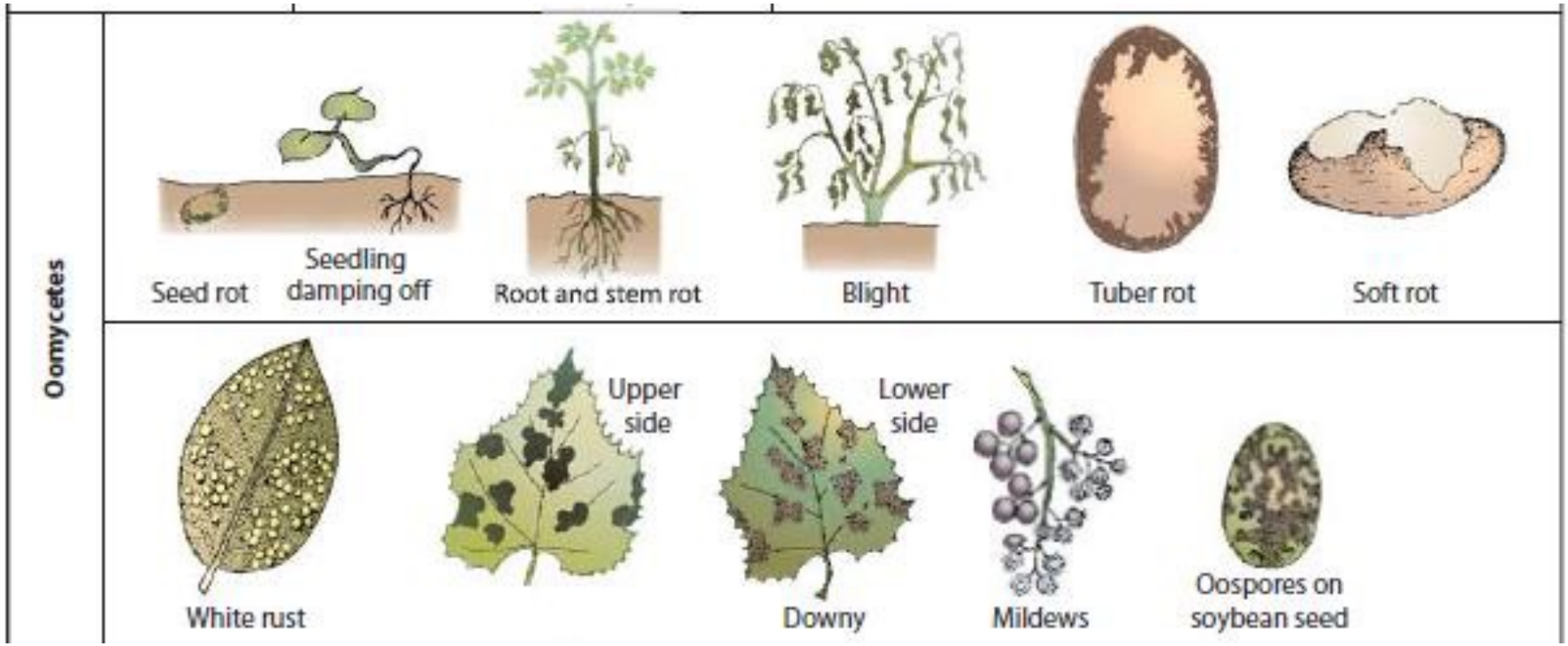
Background on oomycetes

- Look and act like fungi, but they are **NOT** (closely related to diatoms and kelp), usually called oomycetes
- Thrive in aquatic environments and the ability to swim
- Controlled very differently from fungi
- Related to important plant pathogens (*Phytophthora* and *Pythium*)
- Oomycetes are responsible for several notable diseases:
  - Irish potato famine
  - Deforestation in Australia from Phytophthora dieback
  - Cucurbit downy mildew

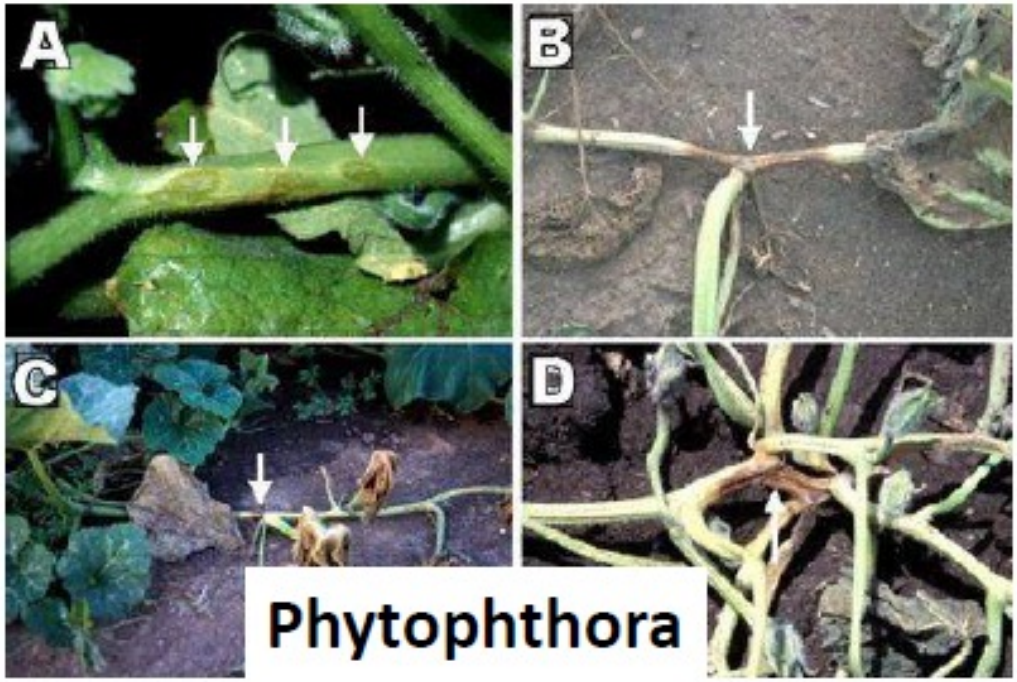


Asexual zoospore discharge of *Phytophthora colocasiae*

Oomycetes: Fungal-like organisms



Known as water molds because they require very moist conditions for spore dispersal


A
B
C
D
Phytophthora


Pythium


Downy Mildew

Background on grapevine DM

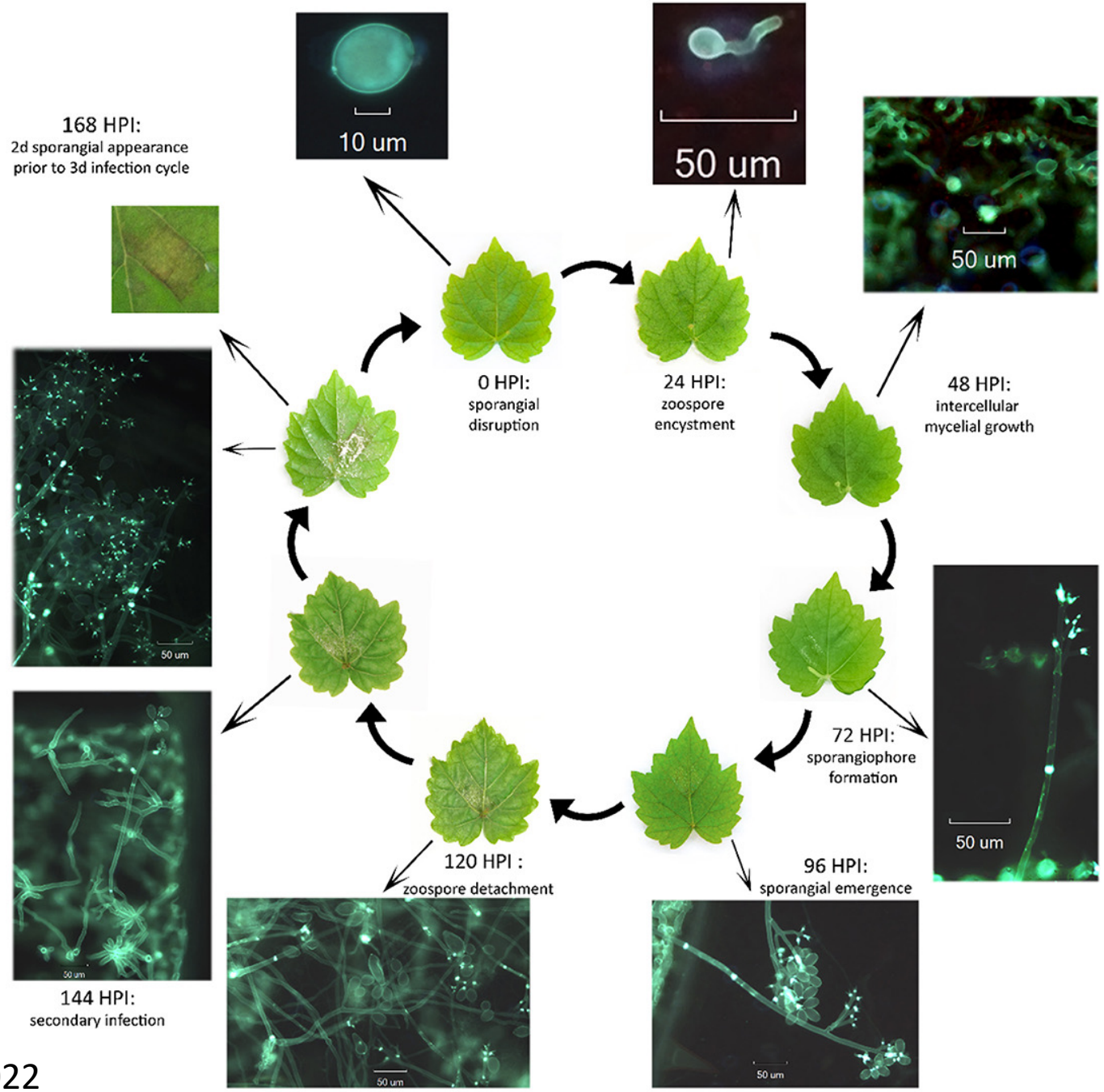


- Downy mildew is a major disease of grapes throughout the eastern United States and much of Europe

- The pathogen *P. viticola:*
  - causes direct yield loss by rotting inflorescences, clusters and shoots
  - causes indirect crop loss by premature defoliation.
  - *Vitis vinifera* cultivars are typically much more susceptible than interspecific hybrids.

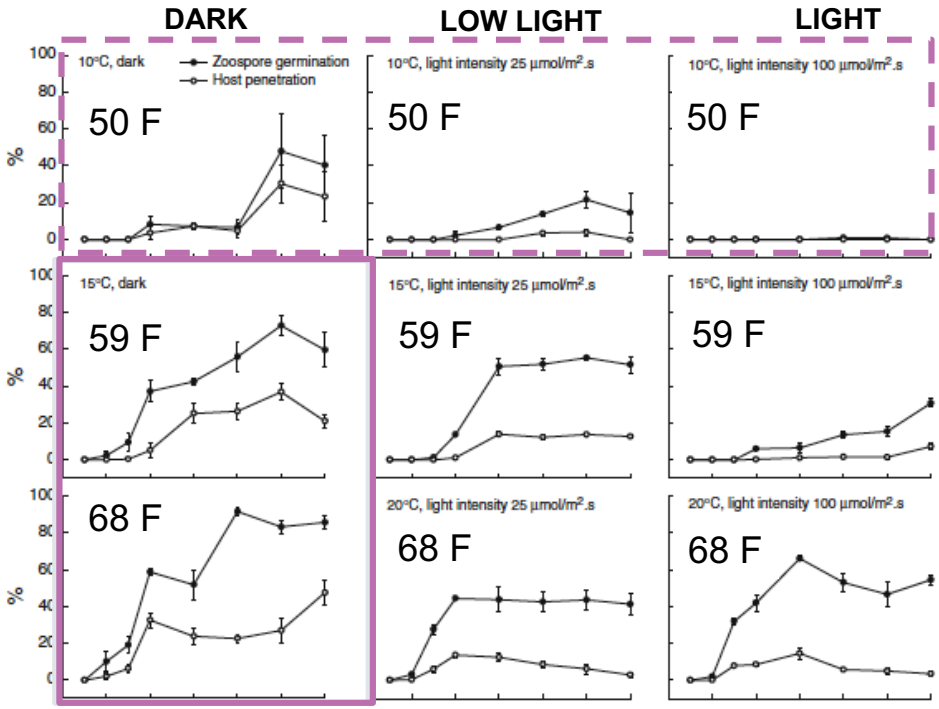
- Lifecycle:
  - The causal pathogen overwinters as microscopic oospores in leaf debris on the vineyard floor which, in the spring, serve as the primary inoculum and germinate in water to form sporangia.
  - When sporangia encounter free water, zoospores are then released and are transferred by rain splash to the surface of the grapevine and enter via grapevine stomata.

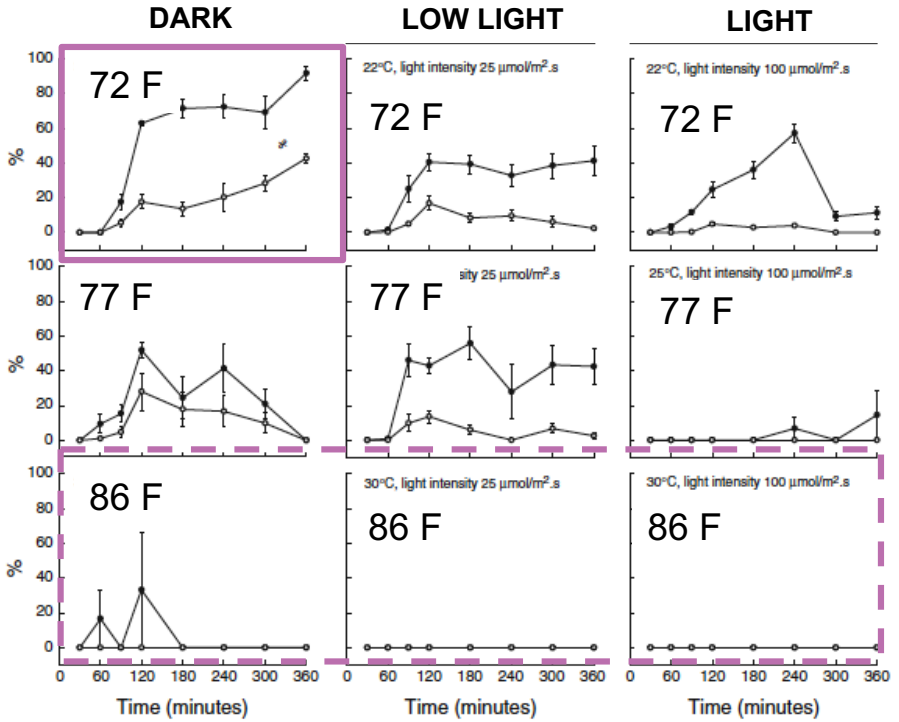
Infection process of *Plasmopara viticola*



Koledenkova et al., 2022

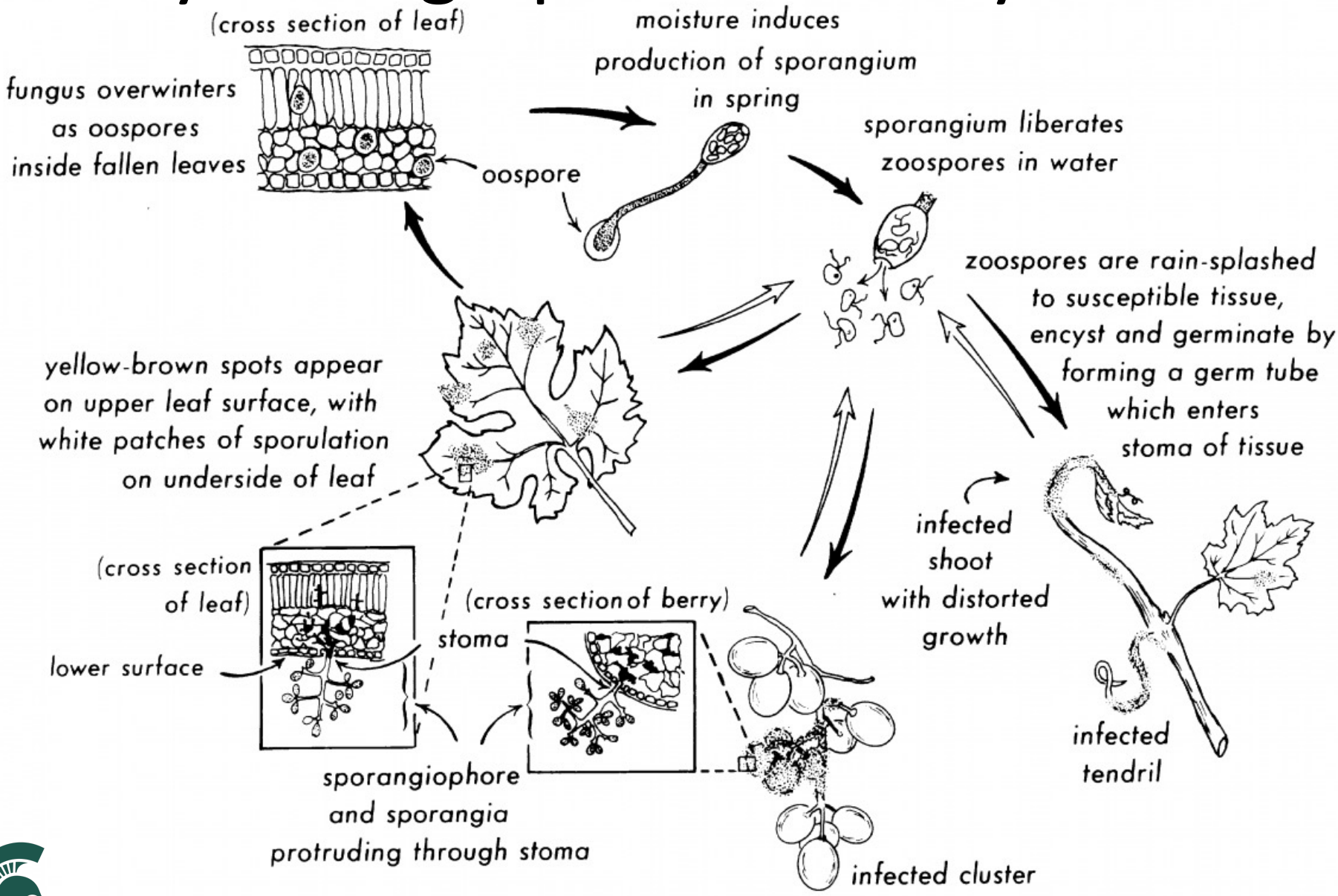
Temperature and Light Intensity Affect Zoospore Germination and Host invasion





Williams et al. 2007. Aus. Plant Pathol. 36:325

Lifecycle of grapevine downy mildew



Symptoms are different on the bottom versus top of the leaves





Leaves will become necrotic over time





Defoliation can become dramatic



Downy mildew can also infect young clusters

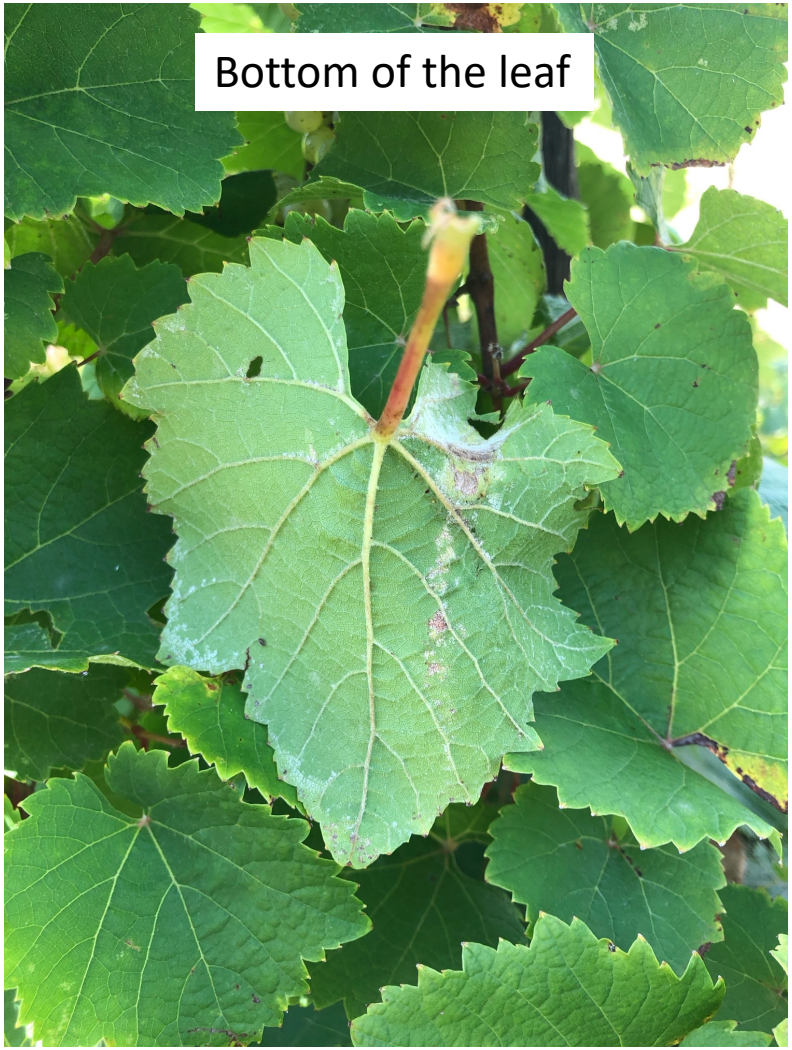




And prebloom flowers/rachis…



Sometimes leaves can be infected with both powdery and downy mildew





Rainfall and high humidity drive epidemics



P. viticola overwinters as dormant oospores within infected leaves on the vineyard floor or within the upper soil layer.

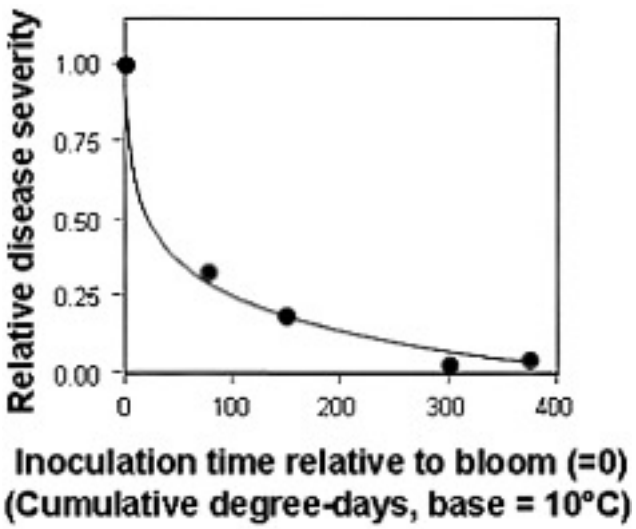
Typically becomes active in the spring about 2-3 weeks before bloom.

Sporangia are produced during rainy periods of approximately 0.1" or more when temperatures are above 52°F, and these are splashed from the soil onto susceptible green tissues to cause the season's first ("primary") infections.

Conditions favoring infection



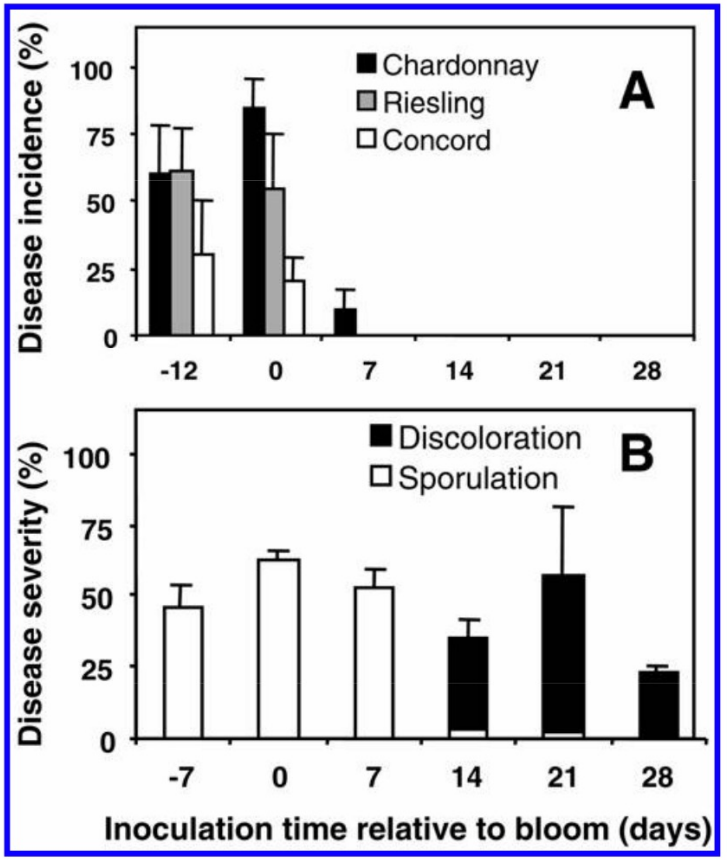
- Bloom is the most critical time (see right)
- At night, during periods of high humidity and temperatures above 55 F.
- Epidemic disease development can then result from repeated cycles of new "secondary" infections
- Sporangia drive these secondary infections and they are only produced at night when the relative humidity is extremely high (>95%; dew usually forms in the morning)



Kennelly, M. M., Gadoury, D. M., Wilcox, W. F., Magarey, P. A., and Seem, R. C. 2007. Plant Health Progress doi:10.1094/PHP-

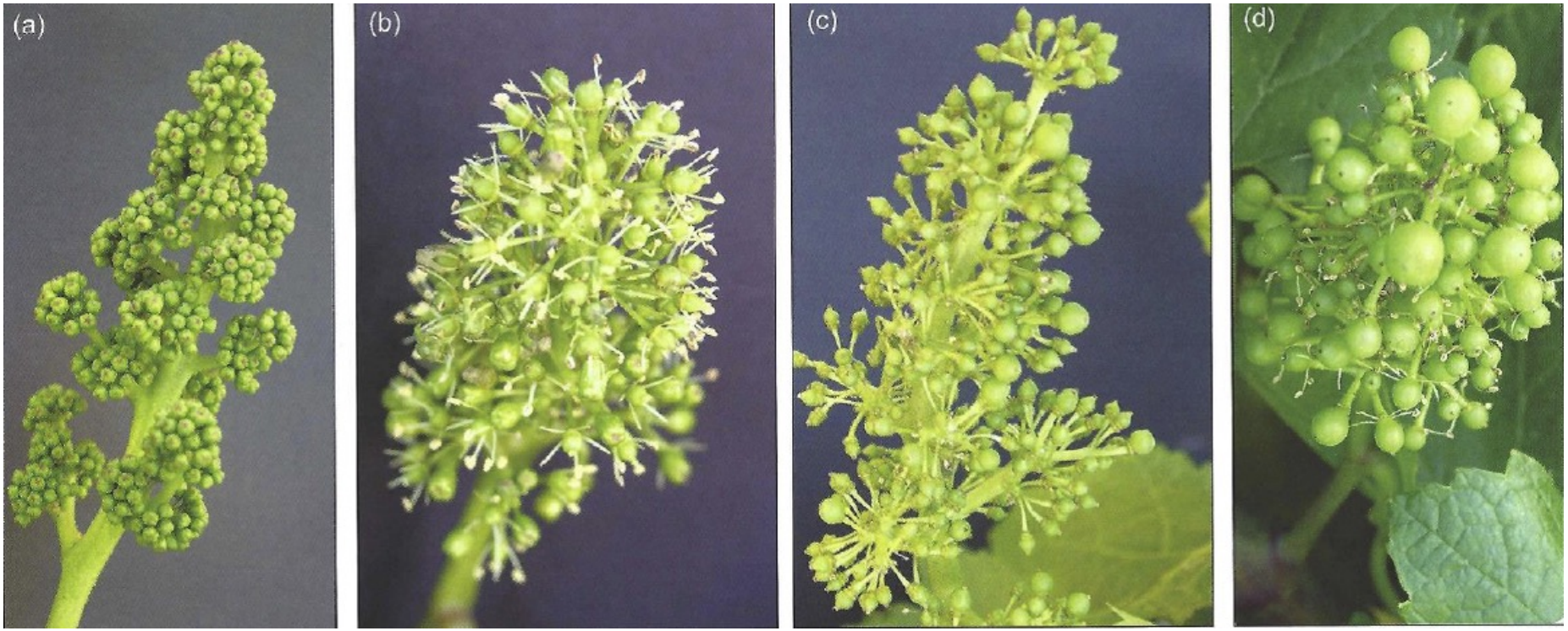
Initially leaves and fruit are susceptible but fruit become resistant over time





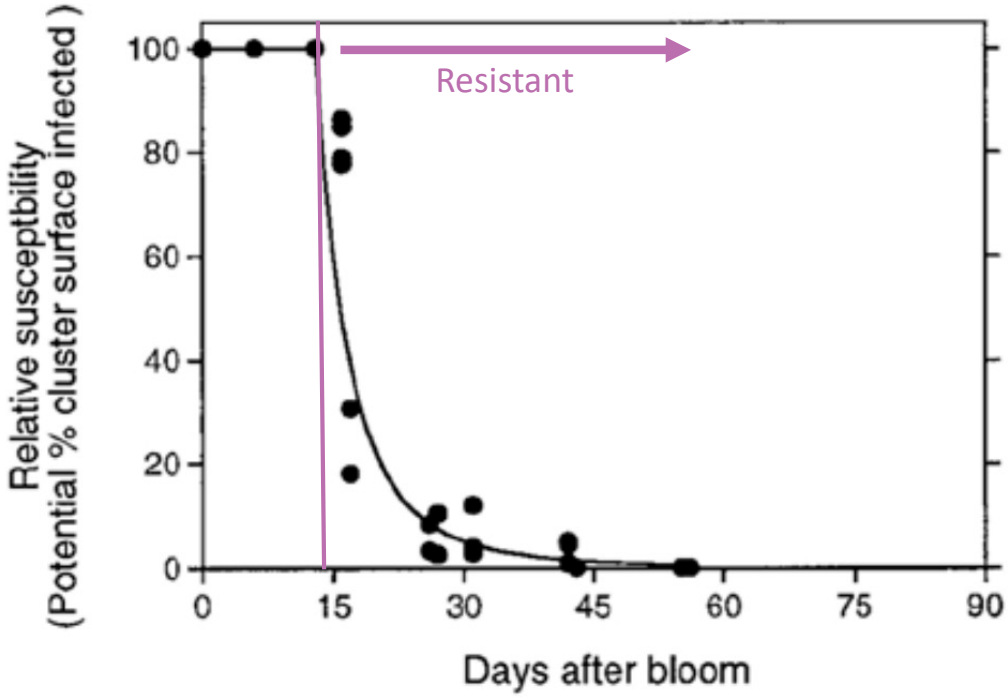
Kennelly et al., 2005. Phytopathology

Critical period for cluster infection



Infections occur at night when temperatures are between 59-72 F and humidity is high

Ontogenic Resistance in Grape (fruits only)



•Begins as the grapes enter véraison (3 to 4 weeks post bloom)

Rogiers et al. 2017. Front. Plant Sci. 8:1629;
Rogiers et al. 2017. Front. Plant Sci. 8:1629;
Ficke et al. 2002. Phytopahtology 92:671

Phases of management for downy mildew of grape

1) Infection before visible symptoms, when protectants can be used,

2) Visible symptoms, when curative products can be applied.

3) Sporulation, when only eradicants are effective.

Fungicides that have some efficacy on DM (bolded)

- FRAC 1
  - Topsin M
- FRAC 2
  - Rovral
- FRAC 3
  - Rally, Procure, Elite, Mettle, Rhyme
- FRAC 4
  - Vangard, Scala
- FRAC 11
  - Abound, Sovran, Flint Extra and Inuity
- FRAC 13
  - Quintec
- FRAC 17
  - Elevate
- **FRAC 21**
  - **Ranman**
- **FRAC 40**
  - **Revus**
- **FRAC 44**
- **FRAC M1, M2, M3 and M4**
  - **Copper, sulfur, mancozeb, ziram, captan**
- **FRAC P5-7**
  - **Regalia, Lifegard, Phostrol**
- FRAC U
  - Torino (U6) and Gatten (U13)

None of these are labeled in California except FRAC 11, Copper and Phosphites

This list isn't completely exhaustive and does not include "mixture" products, such as Pristine (11+7), Inspire Super (3+9), Switch (9+12), Luna Experience (3+ 11) or **Revus** Top (3+**40**)

Fungicides are effective







Outside of California We control by PHI



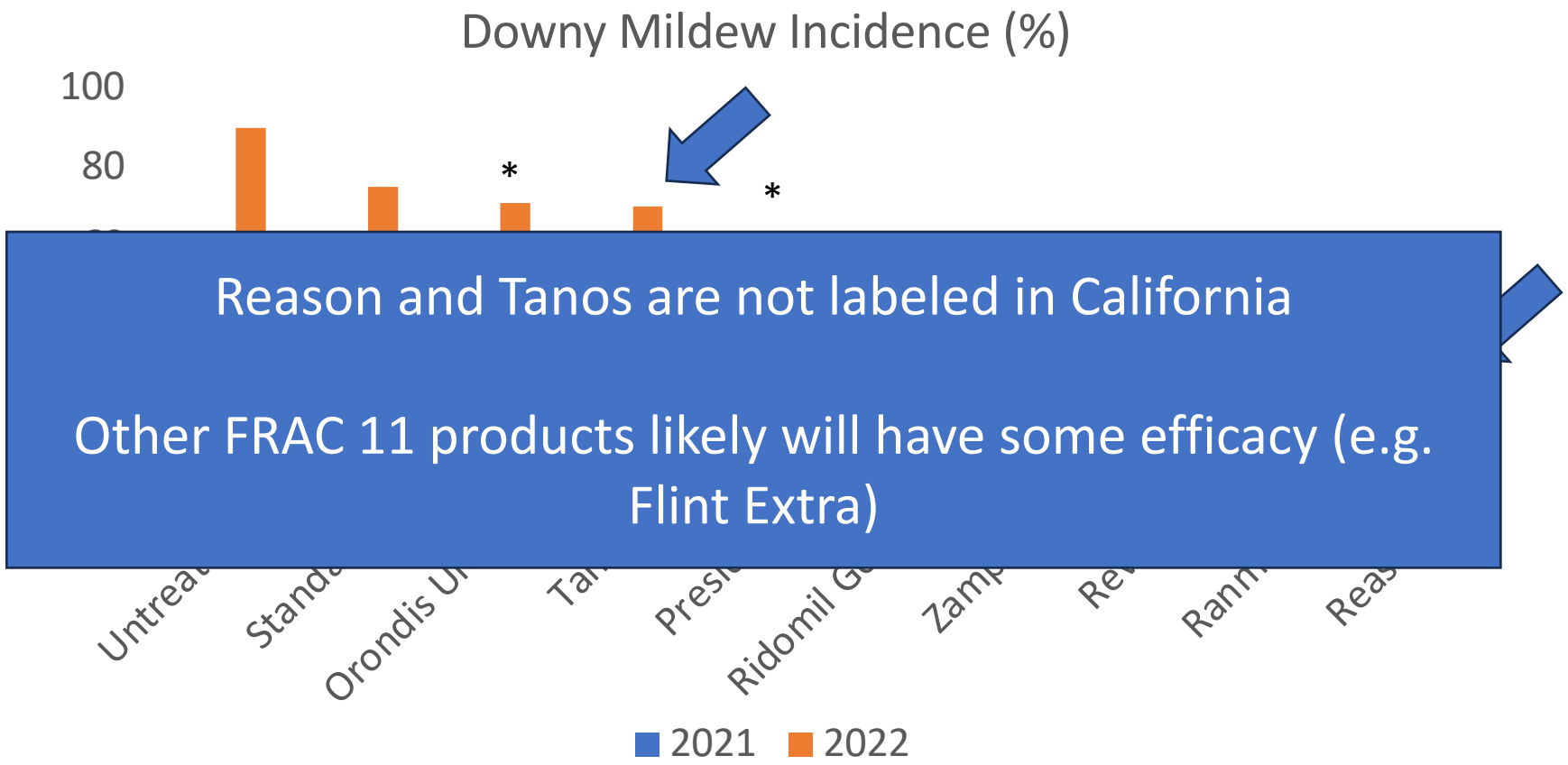
30-day pre-harvest interval products: Ranman (FRAC 21), Reason (FRAC 11)

14-day pre-harvest interval products: Pristine (FRAC 11 + 7), Abound (FRAC 11), Quadris Top (FRAC 11 + 3), Revus (FRAC 40), Sovran (FRAC 11) and Flint (FRAC 11)

0-day pre-harvest interval products: Captan (48-hour reentry interval, FRAC M4), Phosphorus acids (FRAC 33) and Copper (FRAC M1)

*Growers need to be mindful of phytoxicity issues (e.g. Revus Top)

Field Trials at TNRC on Downy Mildew - Niagara (2021 and 2022)

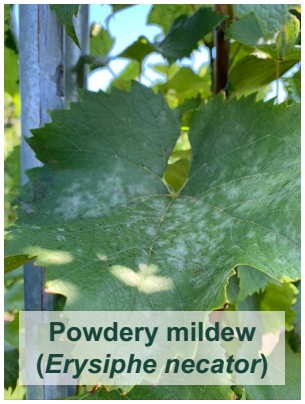


2 applications mixed in with a program of Manzate / Rally

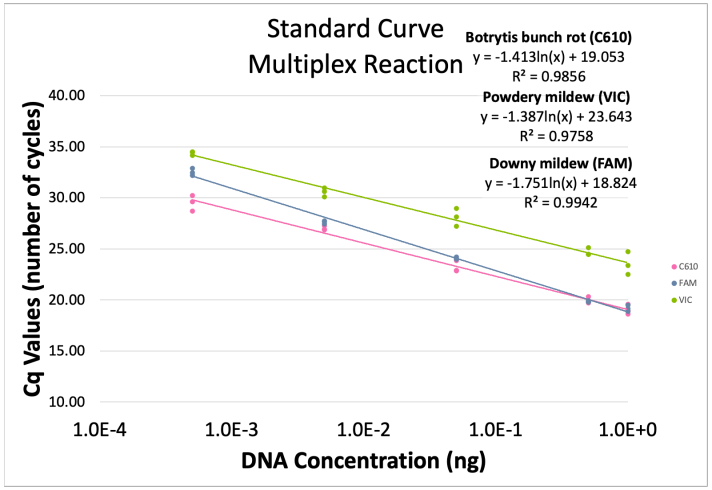
Detection of downy mildew in vineyards with molecular markers



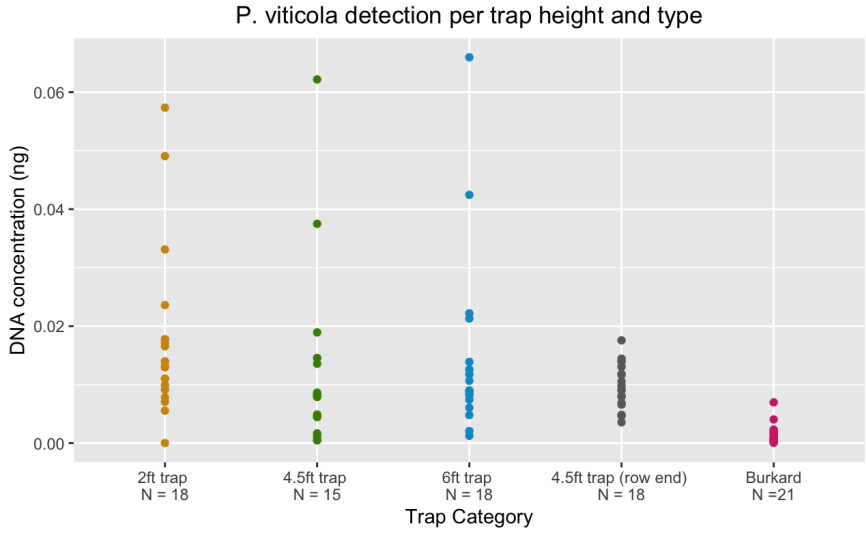




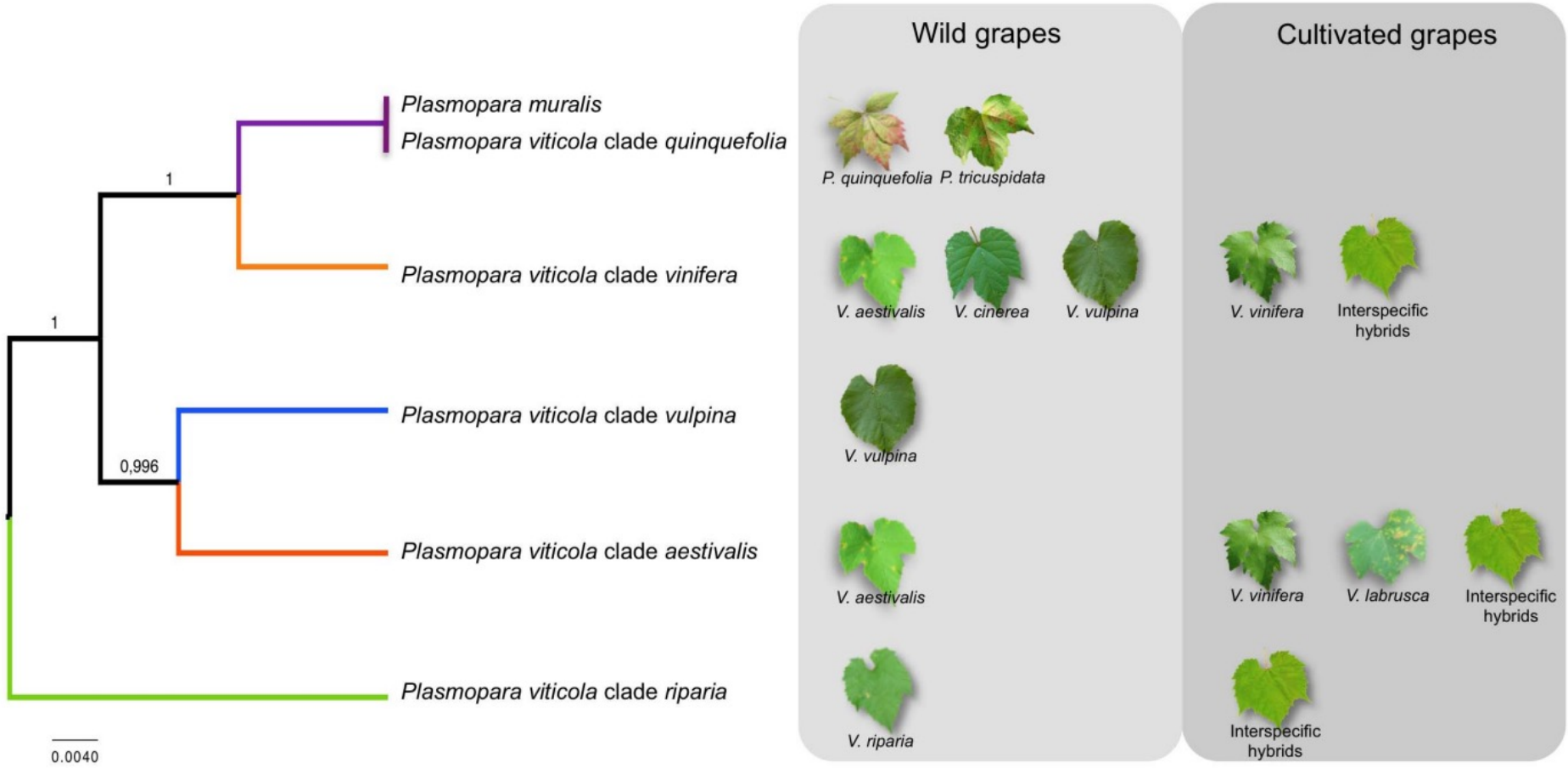




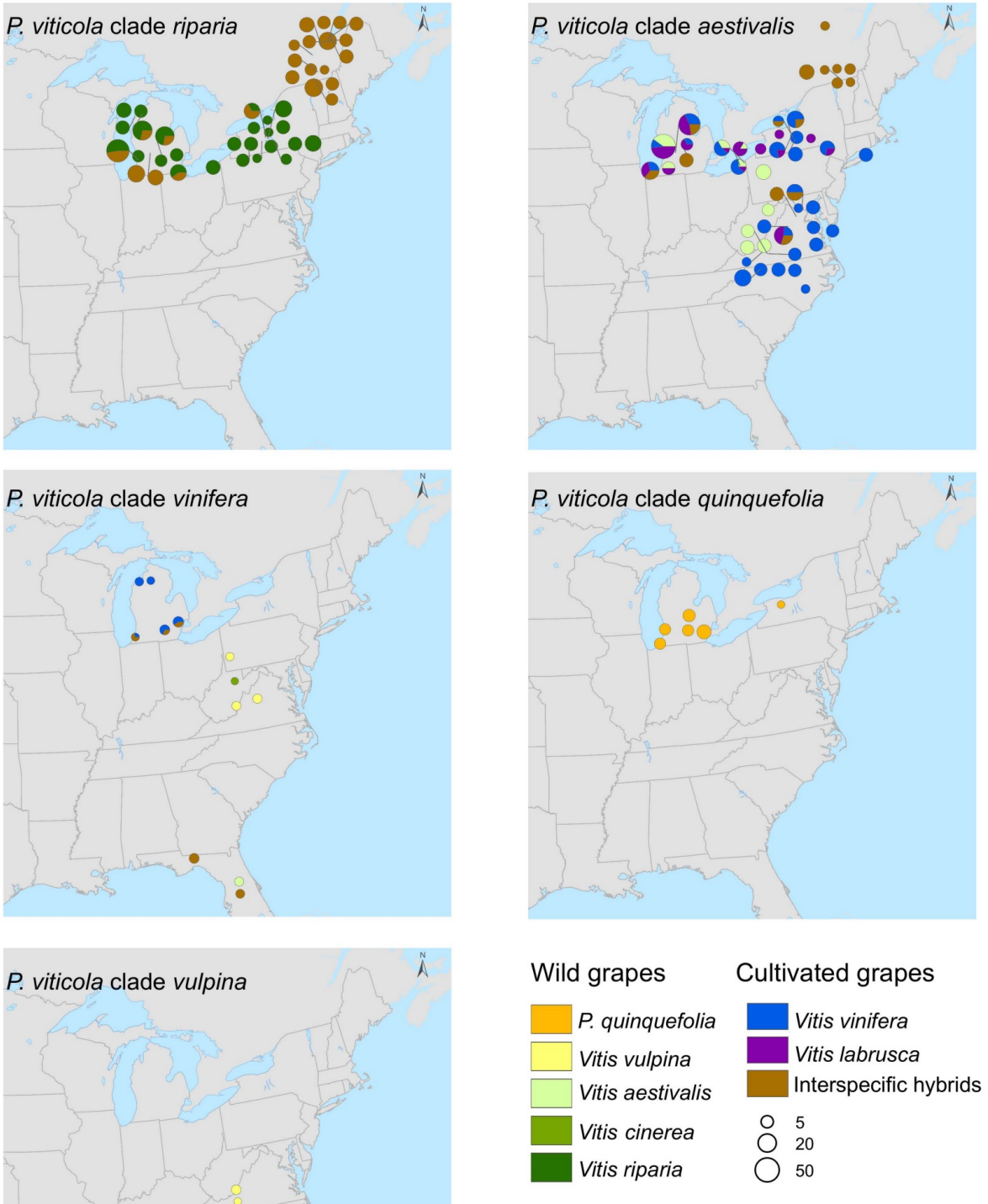
Detection limit: <0.5 pg



There are population differences within *Plasmopara viticola*

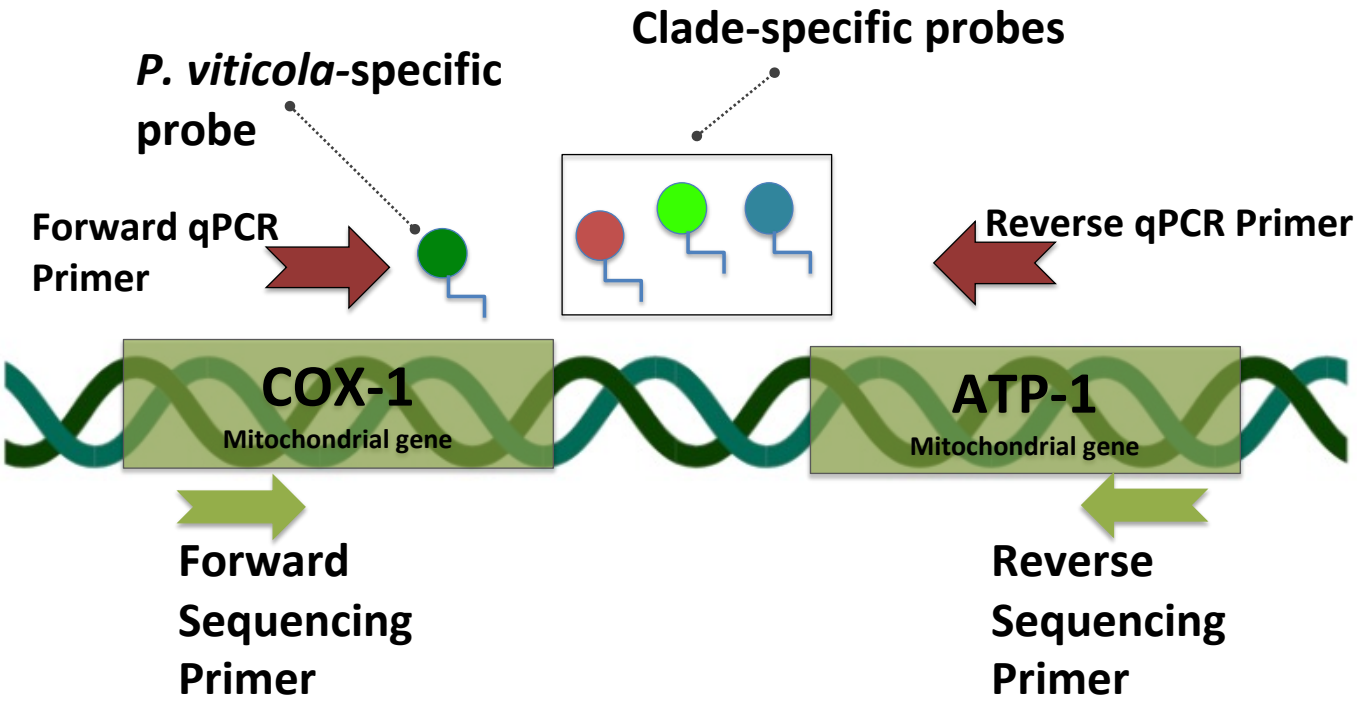


Population differences within *Plasmopara viticola* in Michigan



Rouxel et al., 2014

It might be important to go deeper with these molecular tools, but why?

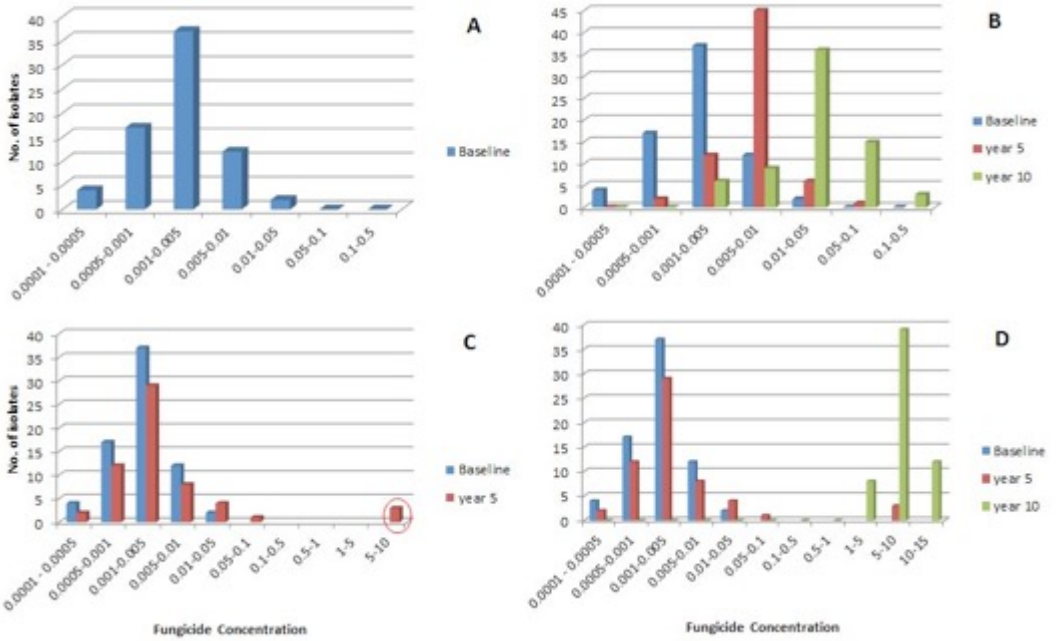


These tools should be helpful for investigating fungicide resistance

What is fungicide resistance?

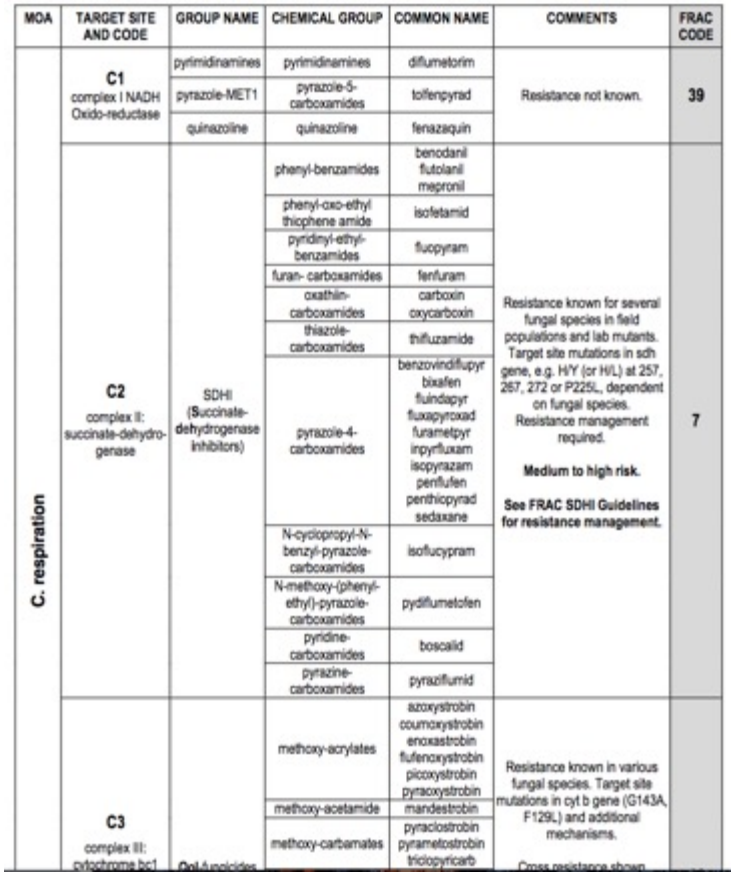
- …when a pathogen population changes from being **sensitive** to a fungicide, to one that is **insensitive** or less sensitive to a fungicide.





How does resistance develop?

- Population diversity (mutations present in some members)
- Continued Selection
- Fungicide Resistance Action Committee: http://www.frac.info/



MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
C. respiration	C1 complex I NADH Oxido-reductase	pyrimidinamines	pyrimidinamines	diflumetorim	Resistance not known.	39
		pyrazole-MET1	pyrazole-5-carboxamides	tolfenpyrad		
		quinazoline	quinazoline	fenazaquin		
	C2 complex II: succinate-dehydro-genase	SDHI (Succinate-dehydrogenase inhibitors)	phenyl-benzamides	benodanil flutolanil mepronil	Resistance known for several fungal species in field populations and lab mutants. Target site mutations in sdh gene, e.g. H/Y (or H/L) at 257, 267, 272 or P225L, dependent on fungal species. Resistance management required. **Medium to high risk.** **See FRAC SDHI Guidelines for resistance management.**	7
			phenyl-oxo-ethyl thiophene amide	isofetamid		
			pyridinyl-ethyl-benzamides	fluopyram		
			furan- carboxamides	fenfuram		
			oxathiin-carboxamides	carboxin oxycarboxin		
			thiazole-carboxamides	thifluzamide		
			pyrazole-4-carboxamides	benzovindiflupyr bixafen fluindapyr fluxapyroxad furametpyr inpyrfluxam isopyrazam penflufen penthiopyrad sedaxane		
			N-cyclopropyl-N-benzyl-pyrazole-carboxamides	isoflucypram		
			N-methoxy-(phenyl-ethyl)-pyrazole-carboxamides	pydiflumetofen		
			pyridine-carboxamides	boscalid		
			pyrazine-carboxamides	pyraziflumid		
	C3 complex III: cytochrome bc1	QoI-fungicides	methoxy-acrylates	azoxystrobin coumoxystrobin enoxastrobin flufenoxystrobin picoxystrobin pyraoxystrobin	Resistance known in various fungal species. Target site mutations in cyt b gene (G143A, F129L) and additional mechanisms. Cross resistance shown	
			methoxy-acetamide	mandestrobin		
			methoxy-carbamates	pyraclostrobin pyrametostrobin triclopyricarb		

Many modes of action (MOA) for various fungicides

Mode of Action – defines how the product actually affects the fungus

Separate from fungicide mobility – how the fungicide moves in plants

Examples

Demethylation inhibitor (DMI) or FRAC 3 compounds – inhibits a specific enzyme in fungi that is important in sterol production

- Sterols are necessary in fungal cell membranes
- Lack of Sterols result in abnormal fungal growth

Quinone outside inhibitors (QoI) or FRAC 11 (Strobilurins) – inhibit mitochondrial respiration, stopping energy production, and resulting in fungal death

- Effective on germinating spores and early fungal growth only

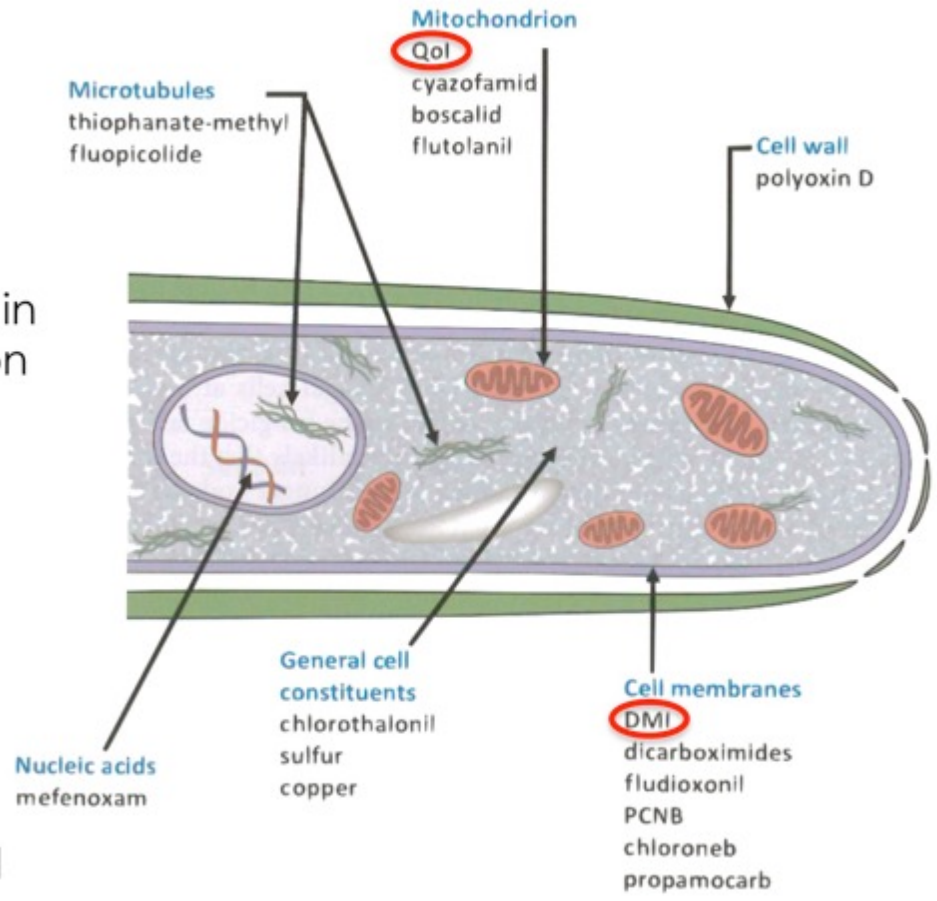


Image Credit: Fig. 2.4 from "A Practical Guide to Turfgrass Fungicides" by Richard Latin, Purdue University





Fungicide resistance in downy mildew – different control products are used

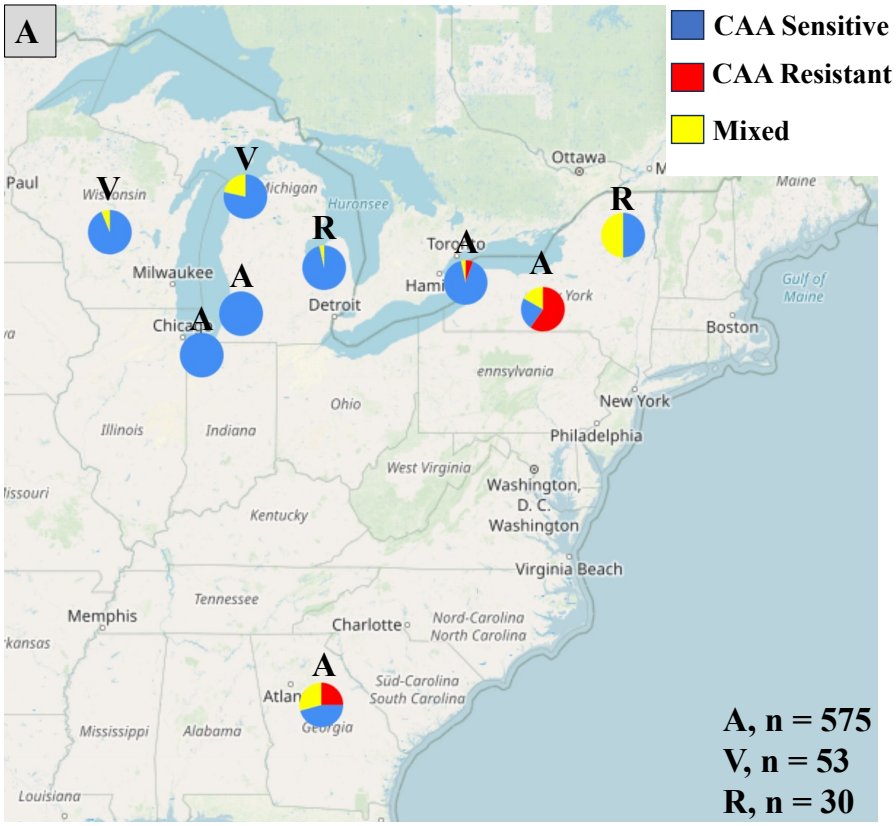
None of these are labeled in California except FRAC 11, Copper and Phosphites

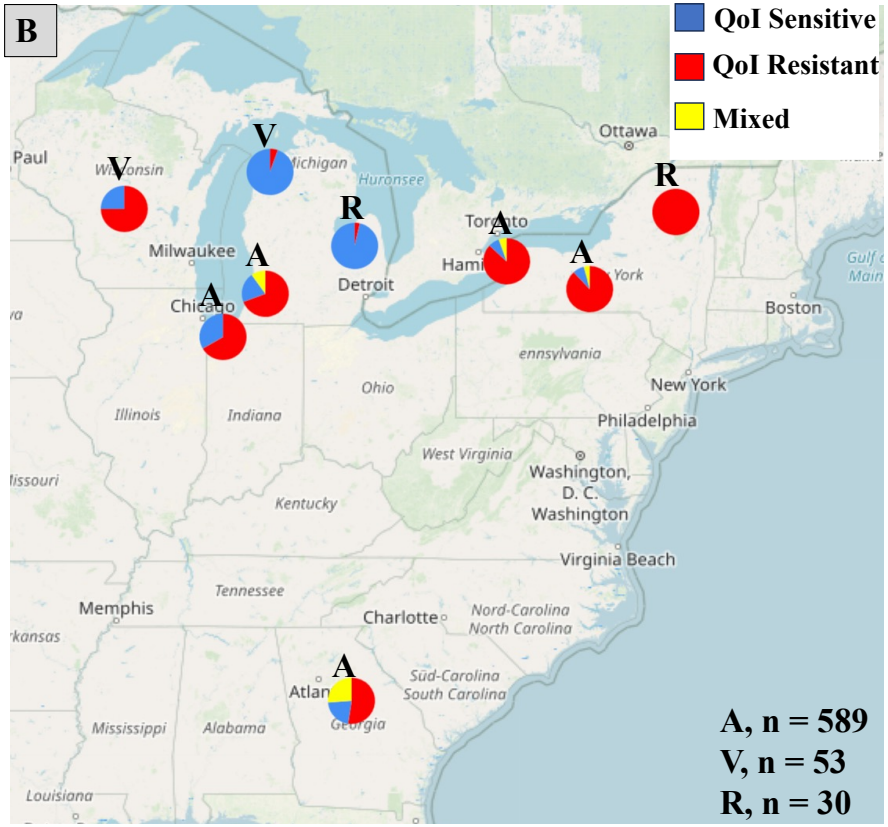
Active ingredient	Product and Manufacturer (City, State, Country)	FRAC	Target site	Resistance in Oomycetes?	Molecular mechanism of resistance identified in oomycetes?
					ge in
					n in DE-V204)
Mefenoxam	Ridomil, Syngenta (Basel, Switzerland)	4	RNA polymerase I	Yes	This is complex
Mandipropamid	Revus, Syngenta (Basel, Switzerland)	40	Cellulose synthase	Yes	G1105W/V amino acid change in cellulose synthase gene (cesA3)
Ametoctradin + dimethomorph	Zampro, BASF (Ludwigshafen, Germany)	45 + 40	cyt b gene (Qo site, stigmatellin binding sub-site)[3] + Cellulose synthase	Yes for both components	Yes, S34L amino acid change in Pl. viticola in the cyt B gene + G1105W/V amino acid change in cellulose synthase gene (cesA3) (dimetomorph)





Results of Survey (2021) for CAA / QoI DM **resistance**





Conclusions

FRAC 11 and 40 resistance mutations were found in many locations surveyed. Work needs to be expanded to other FRAC groups no resistance mutations observed for FRACs 21 and 45.

Sharma et al, 2023. in preparation

Options for managing fungicide resistance

- **General recommendations**
  - Don’t apply half rates
  - Rotate FRAC codes
  - Keep inoculum low in your vineyard and target sprays around bloom
  - Use dormant sprays?***
- **Fungicides unlikely to develop resistance**
  - Manzate (FRAC M3)***
  - Captan (FRAC M3)***
  - Sulfur (FRAC M2)
  - Phostrol (FRAC P)
  - Lifegard (FRAC 44)
  - PreVam (FRAC NC)
  - Stargus (FRAC 44)
  - Kaligreen (FRAC NC)
  - JMS Stylet Oil (FRAC NC)
  - Serenade Max (FRAC 44)
- **Alternative FRAC codes will be important in managing resistance**.



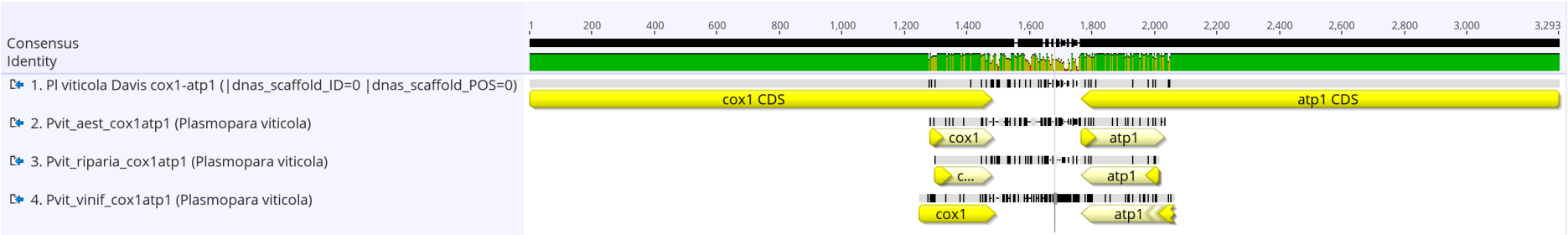
FRAME networks

We think California has a unique clade of *Plasmopara viticola*

- The main Plasmopara viticola in the world is *Plasmopara viticola* clade *aestivalis*

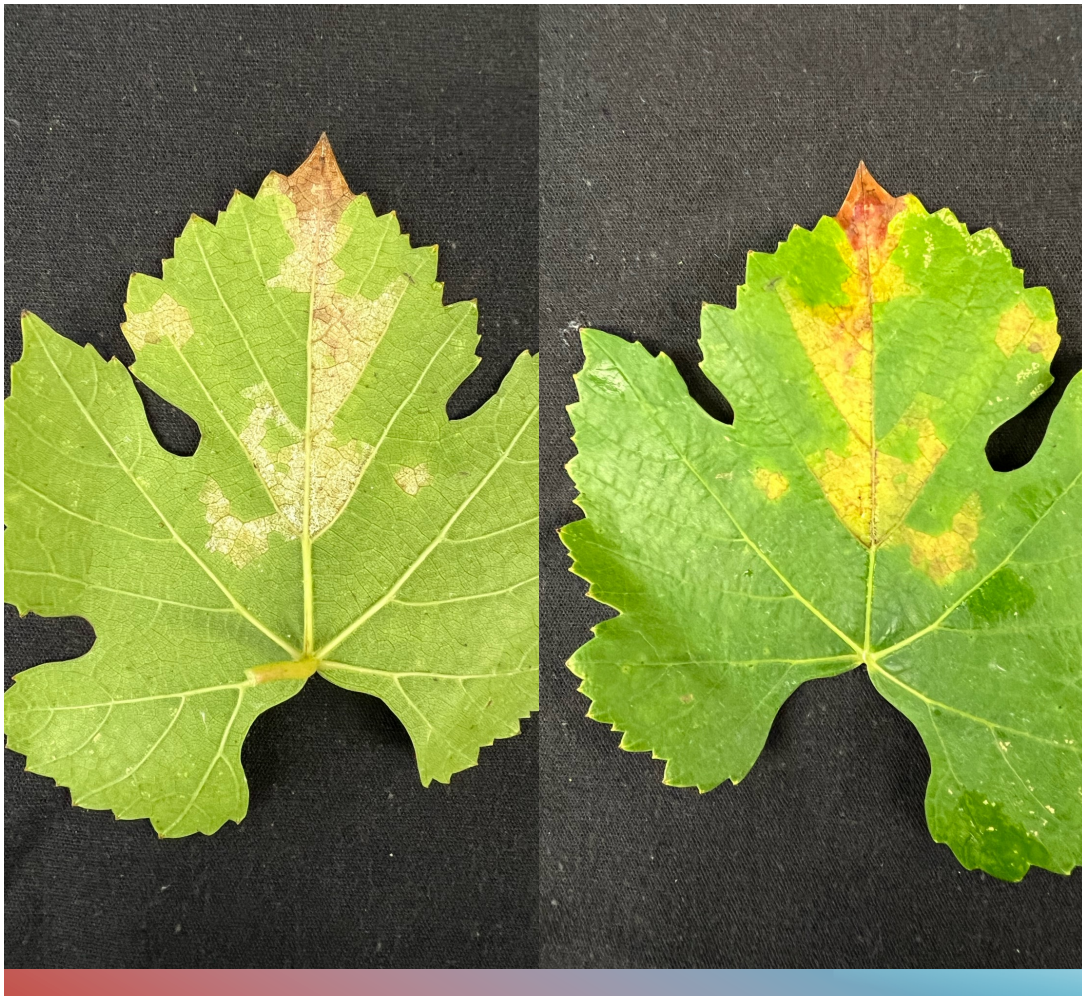


- So far we think this because…
  - Unique mitochondrial genes
  - Slightly different ITS sequence
  - Different short read genome from the UC Davis arboretum (collaboration with Dr. Frank Martin)
  - Is difficult to sporulate and grow on Chardonnay
  - We suspect *Vitis californica* to be an alternate host



Confirming downy mildew in 2026

- We have received samples in my program in 2022 and 2026
- What is different in 2026 is that several samples were sporulating
- In 2026 ‘Pinot Noir’ and ‘Chardonnay’ from Sonoma on June 2
- Reports also from Napa thanks to Monica Cooper

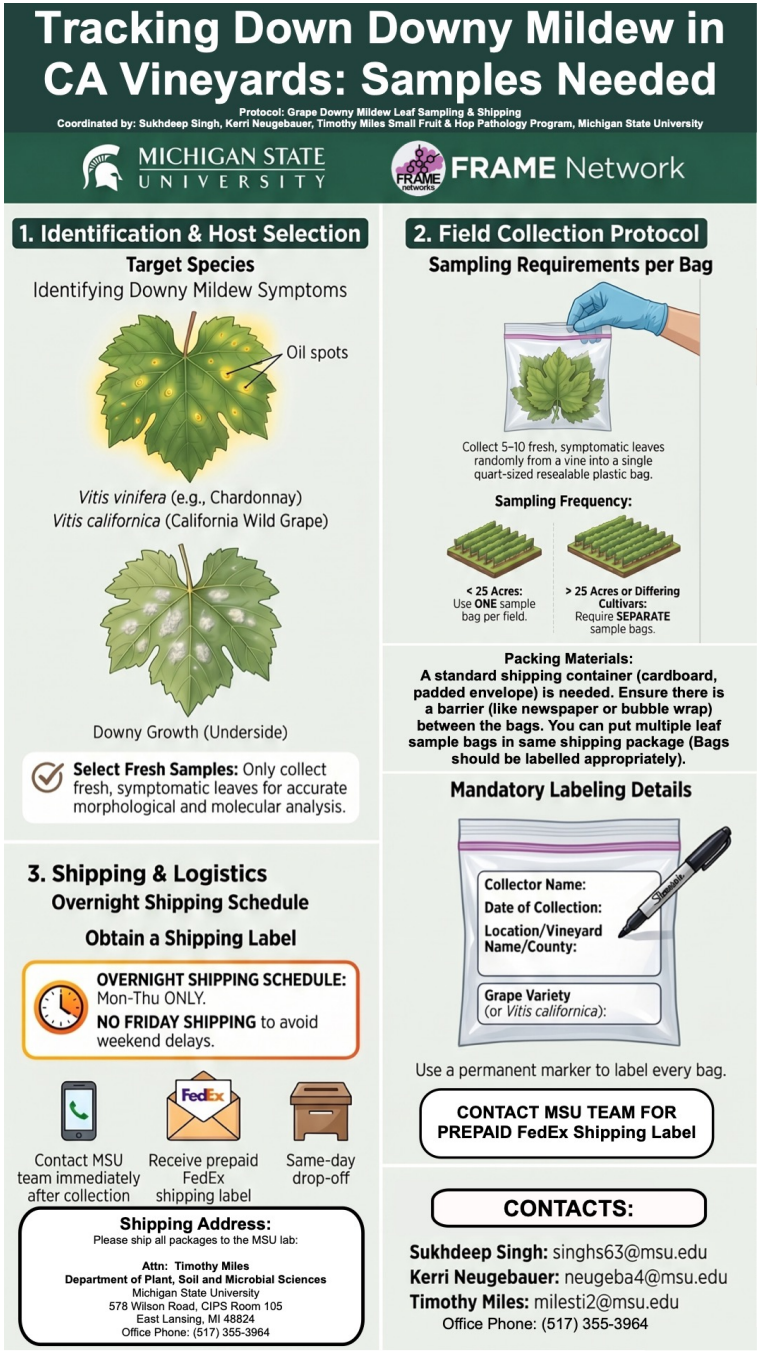


Survey flyer – thank you!

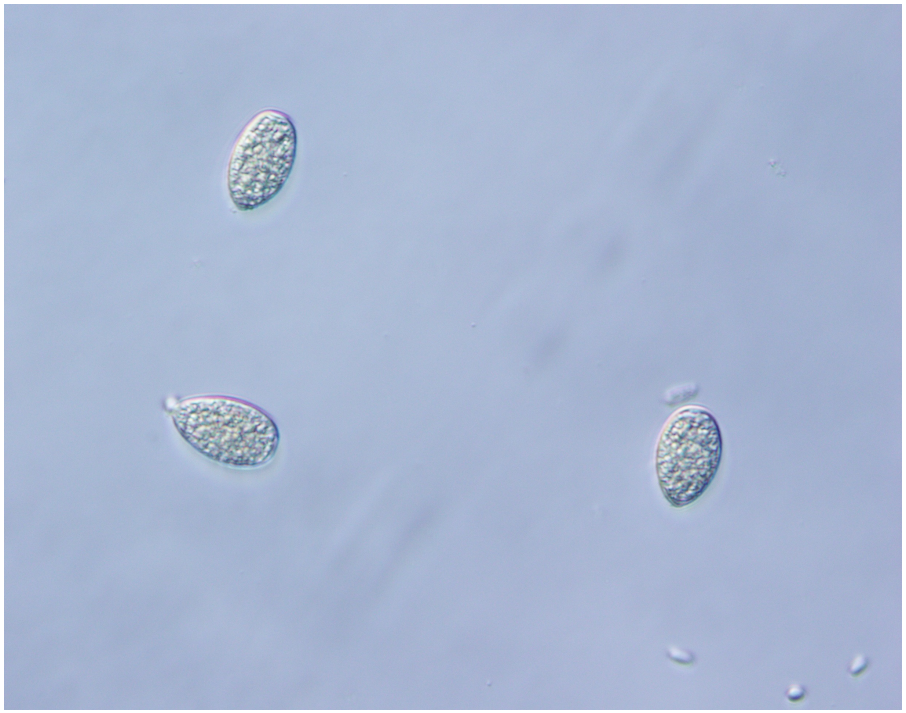
We received 5 packages and a total of 19 sites between 6/2/2026 and 6/10/2026

A total of 7 cultivars

10 samples had visual sporulation



We confirmed DM microscopically on those 10 samples





Take home messages for managing downy mildew

- Prevent early disease establishment on leaves and destructive cluster infections during the prebloom and early postbloom periods
- Utilize multisite fungicides to manage resistance (e.g. Copper, Phosphites)
- Beware of issues with phytoxicity (didn't discuss). Copper etc.
- Phosphites is also an excellent option that is systemic.
- Limit secondary spread on the foliage during the summer and early fall. The timing and intensity of these sprays should be determined by
  - 1) varietal susceptibility,
  - 2) weather conditions, and
  - 3) the availability of downy mildew inoculum

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Building the Latest Understanding in Extension – Disease management that Yields New And Meaningful Outputs

MICHIGAN CRAFT Beverage Council

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FRAME networks

Michigan Grape Society

MICHIGAN Wine Collaborative

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AgBio Research

Michigan State HORTICULTURAL Society

THE BLUEBERRY PEOPLE

MBG Marketing

Growing The Naturipe Way

Michigan Department of AGRICULTURE & Rural Development

MICHIGAN Blueberry COMMISSION