Grape Disease Control, June 2023

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Cornell Grape Pathology

Welcome to my third annual Cornell Grape Disease Control article (belatedly published this year, sincere apologies). If this is your first time reading this guide, allow me to take a moment to introduce myself. My name is Katie Gold, and I joined Cornell University as an Assistant Professor of Grape Pathology at Cornell AgriTech in Geneva, NY on February 1, 2020, about five weeks before the global pandemic began. Along with applied grape disease management, my lab's research focuses on early disease detection for effective management intervention. We specialize in non-destructive, sensing-based methods of detection deployed at a range of scales, from handheld sensors to autonomous robots and satellites. We conduct much of this research within our extensive fungicide efficacy trials in our pathology vineyards in Geneva, NY. To say that my first three years on the job have been eventful is likely an understatement, as they have included a global pandemic, three NASA grants (the first the agency has ever awarded to a "card carrying" plant pathologist), a baby (now toddler), and three record breaking growing seasons. Despite the times, I am hopeful for a bright future and look forward to continuing to get to know the NY grape and wine community, both virtually and in person.

This article will discuss news and updates to fungicides labeled in NY since 2022, (re)introduce the major grapevine diseases in New York and relevant recent research findings, discuss cultural practices that can reduce disease inoculum in vineyards, and outline the basics of a strong management program at different growth stages. All sections of this document have been tweaked since its last publication in Spring 2022. Notable additions to this document include are **thoughts on managing FRAC-40 resistant downy mildew (page 15) and biopesticides for grape disease control (page 34).** As a reminder, growers on Long Island should check labels to ensure recommended products are labeled for use there. And, as always, **read the pesticide label prior to use.**

May 2023 Freeze Event and Implications for Disease Control

One of the minor advantages to publishing this article so egregiously late this year is that I get to add a section commenting on how the May 2023 freeze event might impact disease management. For those who are reading this article but not based in New York, our industry suffered a record-breaking late season freeze overnight from May 17 – 18 impacting tender shoots. This will push back vine phenology on hard hit vines as they send out new buds ("secondaries"). Overall, we expect to see reduced yields due to this freeze damage, but not due to any direct increase in disease severity, though we may see indirect effects. For example, secondaries will experience the critical cluster control period (immediate pre-bloom to immediate post-bloom) later than they do typically due to their late growing start. This means it is important to be aware of their growth and stages, as control will be crucial later into the season than one normally anticipates, and if you slow down on control too early, your clusters may be unprotected during this important phase. Another indirect effect may be related to the fact that vines that experienced hard freeze damage may have fewer clusters than they would have normally. This means that cluster rot control in the late season will be especially important to ensure adequate yield, as there will be far less room for error. I was additionally asked to share thoughts on whether the dead shoots may serve as an inoculum harbor for some of our most important pathogens. While I hesitate to speak definitively without research to back me up, overall, I am not concerned about this because our most important diseases (Powdery Mildew and Downy Mildew) are obligate biotrophs, which means they require living tissue to complete all aspects of their life cycle, thus they cannot eat the dead shoots even if they so wanted to. The dead shoots may indeed harbor opportunistic nectrophs and saprophytes (consumers of dead tissue), but these should not pose a problem under a standard disease control program.

Spanish Language Translation

This year I am thrilled to share that **this guide is now available en español**! PhD Candidate Kathleen Kanaley, graduate student in my lab, translated the core information of this manifesto into Spanish as part of her Spring 2023 Cornell AgriTech Extension-ship (like a teaching assistantship, but for extension!). To access her translation, please use the following link: https://cornell.box.com/v/cornellGDC2023spanish. Thank you, Kathleen, for your herculean effort to accurately translate this document and above all else, your dedication to inclusive extension education. You inspire me, and I am so proud to be your doctoral advisor. Kathleen just completed her second year of graduate school and passed her PhD candidacy exam this recent May. Way to go Kathleen!

Cornell Grape Pathology News

Since the publication of this update last year, the Gold Lab has welcomed two new members and bid a fond farewell to another. We additionally received two large federal investments in our research, from NASA and USDA NIFA respectively. Postdoc Dr. Nikita Gambhir moved on to a full time, permanent position as a Research Discovery Scientist at FMC Corporation in the Fungicide Discovery Biology section at the end of March 2022. Dr. Gambhir has been thriving in this role, be on the lookout for her newly discovered products in our pathology vineyards over the next decade! In January 2023, we welcomed Dr. Saeed Hosseinzadeh as a new postdoc on our fungicide activity sensing project. Dr. Hosseinzadeh earned his PhD from Cornell University in the lab of Dr. Michelle Heck in December 2022 where he studied multi-omic approaches to understand plant-viral-vector interactions. In August 2022 we welcomed new PhD student Jackie Eller to the Gold Lab. Jackie comes to Cornell by way of California State University – Northridge, where she earned both her BS and MS in Geography. Jackie is funded under the newly established NASA Acres Domestic Agriculture consortium, a cross-disciplinary consortium designed to strengthen all aspects of US agriculture- including specialty crops such as grape! As a founding member of this consortium, I have taken on the role of Pest and Disease Risk Assessment Lead, which will provide me with a platform to improve connections between stakeholders, academics, and NASA to foster and enhance disease and pest risk assessment with NASA data across all aspects of US agriculture. For more on NASA Acres, you can visit the following link: https://www.nasaacres.org/. For more on the specific research project the Gold and Jiang labs will be undertaking as part of this consortium, please visit the following articles: https://cals.cornell.edu/news/2023/05/bringing-nasa-technology-down-earth-agriculture and https://www.goodfruit.com/disease-detection-from-space/.

Additionally, the USDA NIFA SCRI VitisGen3 was funded and the Gold lab has officially joined the team to lead the "Sticks in the Ground: Designing Disease Control Programs for Moderately Resistant Varieties," objective. We will be conducting VitisGen's first ever field trials to design low-input disease management programs for their new varieties. This grant extends NIFA-SCRI's previously funded VitisGen1 and 2 projects, a decade-long collaboration whose national team of Cornell-led scientists discovered many of the genes that control important traits in grapevines, such as disease resistance, insect resistance, and fruit and wine quality. In May 2023, we (here I use the royal "we," as Dave Combs, our Field Research Manager, did all the hard work!) planted two new vineyards as part of this collaborative grant. We will be evaluating how spray programs driven by powdery mildew epidemiology controls disease in moderately disease resistant NY06 and assessing the benefit of stacked resistance genes in 6 variety fungicide trial. Within these trials we will be focusing on both conventional and biopesticides, seeking to optimize biopesticide use by variety and phenology. We will be collaborating closely with Drs. Lance Cadle-Davison and Yu Jiang who are leading the computer vision objectives to blend our lab's expertise in early disease detection into their robotics goals. Our lab will use the new hyperspectral field and lab robots Jiang will develop in these trials to detect disease before visible symptoms appear, and in the lab to begin characterizing the mechanisms behind more complex forms of disease resistance. For more on this project, please see the following article: https://news.cornell.edu/stories/2022/11/autonomous-robots-help-modernize-grape-wine-industry.

Fungicide Changes, News, and Reviews

This section will cover new or newish products that became available in 2023/2024, changes to existing products, as well as products in the pipeline expected to become available to NY growers in the next couple years.

New to New York

Full Efficacy Data Available:

Gatten: Gatten (flutanil) is a new fungicide from Nichino with a unique mode of action (MOA; FRAC U13) labeled for use in NY as of the 2020 season for powdery mildew control. It provided excellent control of powdery mildew over three years of testing at Cornell in its current incarnation from Nichino and previously as a numbered compound from Valent. This product does not have any variety restriction. For resistance management's sake, I do not recommend this product be used more than 1-2 times a season-- and definitely not twice in a row without rotating to an unrelated FRAC group in between. As it is a unique MOA, it has an excellent place as a rotational "big gun" to take the pressure off other premium materials in other groups.

Intuity: Intuity (mandestrobin) is a strobilurin (FRAC 11) fungicide from Valent labeled for Botrytis and powdery mildew use in NY in the 2020 season. Intuity provided good Botrytis bunch rot control and slight powdery mildew control over three years of testing at Cornell. This product has a 10-day pre-harvest interval and a variety restriction against use on Concord, Niagara, and *V. labrusca* hybrids, or other non-*vinifera* hybrids where crop sensitivity is not yet known. As a resistance stewardship reminder, FRAC 11 fungicides should not be applied more than 2-3x per season and never twice in a row.

Howler: Howler is a biopesticide from AgBiome labeled for powdery mildew, downy mildew, and Botrytis control as of the 2020 season. The active ingredient is the bacteria *Pseudomonas chloroaphis* strain AFS009. We (the royal "we" of Cornell Grape Pathology, referenced from here on thusly) tested this product for powdery mildew, downy mildew, and Botrytis control in 2020, 2021, and 2022. We also tested Howler for black rot control in 2022. Howler performed well in rotation with a commercial standard for PM control and provided moderate control on its own. Howler also provided good botrytis control, moderate black rot control, and moderate downy mildew control. Now that we have 3 years of efficacy data, you can expect to see this product in the next edition of the NY/PA grape pest and disease control guide. As mentioned in the past, this biofungicide has much better efficacy when rotated with a conventional material against powdery and downy mildew. A new formulation known as Howler EVO will be released in 2023 that will reduce the label rates, while not changing the % active ingredient. The original formulation has a label rate range from 2.5 – 7.5 lb/A, so it is important to be sure your material has been thoroughly put into suspension if using the higher rates. Interactions affecting efficacy when Howler is tank mixed with conventional fungicides are not completely understood. Do not allow this product to stay in the spray tank for more than 24hrs before use. Howler has a 0 day PHI and a 4 hr REI.

Theia: Theia (*Bacillus subtilis* strain AFS032321) is a new biopesticide from AgBiome labeled for use in NY as of 2023 (https://www.agbiome.com/theia/). Theia is an OMRI (Organic Materials Review Institute) listed fungicide allowable for organic production. We tested Theia for powdery mildew, downy mildew, and Botrytis control in the 2020, 2021, and 2022 seasons. Overall, we find that Theia provides moderate botrytis and black rot control and moderate control of foliar powdery mildew. Theia provides excellent control of foliar downy mildew when tank-mixed with Revus, and moderate control when the two products were used in rotation. Theia has a 0 day PHI and a 4 hr REI.

Romeo: Romeo is a biopesticide from Wilbur-Ellis labeled in grape for powdery mildew, downy mildew, botrytis, and sour rot control. We tested this product for powdery mildew and downy mildew control in 2020 and 2021 and for powdery, black rot, botrytis, and sour rot in 2022. Romeo provided moderate powdery mildew control and fair downy mildew control. Romeo also provided good control of black rot, moderate control of botrytis, and minimal control of sour rot. Romeo has a 0 day PHI and a 4 hr REI.

Limited Efficacy Data Available:

Ecoswing: Ecoswing is a plant extract biofungicide from Gowan that is newly available in NY that we tested for the first time in our powdery mildew trial in 2022. In 2022 Ecoswing provided good foliar powdery mildew severity control but struggled to control cluster infections. As a caveat, the 2022 powdery mildew trial was a record breaker, so I'm holding off issuing judgement on this product until we see a few years efficacy data. Stay tuned for the 2023 results.

Regalia: Regalia is a plant extract biofungicide from Pro Farm Group (formerly Marrone BioInnovations) that has been tested for many years. While the results have varied when used alone, recent field testing has shown that when this product is tank mixed with **Stargus** (see below) the efficacy of both materials is multiplied. Labeled rates are quite high, and the price is on the higher end of the biofungicide spectrum, but results against black rot rival conventional materials. Regalia and Stargus have a 0 day PHI and a 4 hr REI.

Stargus: Stargus is a microbial biopesticide from Pro Farm Group (formerly Marrone BioInnovations). The active ingredient is the bacteria *Bacillus amyloliquefaciens* strain F727 and was selected intentionally to improve the performance of Marrone's workhorse product Regalia. Stargus is labeled for use in grapes and was tested at UC Davis for Botrytis efficacy (moderate). We tested this product in 2020 and it provided good powdery mildew control. In 2021 we saw that a combination of Stargus+Regalia provided excellent powdery mildew control. In 2022 Stargus+Regalia provided excellent control of black rot. Word is that Pro Farm Group plans to release a pre-mix product in the next few years.

News & Label Changes

Cevya: Cevya (mefentrifluconazole) is a DMI fungicide (FRAC 3) from BASF labeled for use in NY as of the 2020 season for powdery mildew and black rot control. All variety restrictions have been removed from the Cevya label- it is now available for use on Concord and other juice grape varieties. All new product shipping now has the new label on the jug. Any product sitting in inventory from previous years still has the old label on it, however product from 2021 can be used on all grape varieties if the grower has the new label on hand when they are making applications to those previously restricted varieties. Cevya provided good-excellent powdery mildew control over four years of trials at Cornell. In a one-year trial at Penn State University it provided excellent black rot control.

Sovran: FMC has exited the Sovran business and the product is now sold by BASF under the same name. Sovran generics will still be available.

Fracture: Fracture has been dropped by FMC and will be available under the new name ProBlad Verde from SymAgro (https://sym-agro.com/problad/). This product is labeled for use on Botrytis bunch rot, powdery mildew, and anthracnose on grape in NY.

In the Pipeline & Not Yet Labeled

Parade: Parade is a new SDHI fungicide from Nichino that will be registered by end of year for grape powdery mildew control and is expected to receive NY registration within a couple years' time. In 2021 Parade provided good foliar black rot control and variable powdery mildew control. In 2022 Parade provided good foliar powdery mildew severity control, however it struggled to control cluster infections. As a caveat, both the 2021 and 2022 powdery mildew trials were record breakers, so I'm holding off issuing judgement on this product until we see a few years efficacy data. Stay tuned for the 2023 results.

Ensendo: Ensendo is a pre-mix product from AgBiome that combines their biopesticide Howler with a strobilurin (FRAC 11). Ensendo received EPA approval in October 2022, with NY state registration expected later in 2023.

Numbered Compounds: In the 2022 season, we contracted with a variety of companies to assess many numbered, pipeline products compounds in our powdery and downy mildew trials that have pleasantly surprised me with their efficacy. While I cannot yet share more, I am excited about the products broadly in the R&D pipeline and what they will mean for grape disease management in the future.

Early Season Grape Diseases

Though I've titled this section "early season diseases", many of the diseases presented herein pose a threat throughout the season but are referenced thus because they are most critical to control during the early season to ensure a season-long protection and crop quality. Most grape pathogens prefer soft, succulent tissues and immature berries. If disease is allowed to take hold during the early season, late season control will become nearly impossible at worst, and incredibly challenging (and expensive) at best. Early season disease control pays for itself. Management in the early season in New York primarily focuses on five diseases: Phomopsis, black rot, downy mildew, powdery mildew, and occasionally anthracnose. Varieties differ in their susceptibility to these diseases, but generally speaking, *labrusca* type varieties are least susceptible, *vinifera* are the most susceptible, and hybrid varieties are intermediate.

Phomopsis

Phomopsis is a significant problem on Concord and Niagara grapes, though hybrid and *V. vinifera* grapes are susceptible as well. Phomopsis can infect all succulent tissue on grapevines when conditions are favorable. Infections that occur on the developing rachis when clusters first become visible at about 3" shoot growth are most damaging and can result in severe fruit loss. Additionally, infections at the base of green shoots will weaken them and make them more susceptible to breakage.

Broadly, spur-pruned vines will be more susceptible to Phomopsis buildup than cane pruned vines, because more old wood that can harbor inoculum is retained. Phomopsis is particularly efficient at colonizing dead wood, so infected wood left in the trellis can serve as a source of infection for years to come. Removing dead canes, arms, and pruning stubs will significantly reduce Phomopsis initial inoculum.

Phomopsis cane and leaf spot, P. McManus, University of Wisconsin-Madison

Outside of dormant sprays, the critical control period for Phomopsis is the earliest of all the early season diseases, 1-5" shoot growth, and is frequently the first spray made of the season. Concord and Niagara growers should NOT skip this spray! Several fungicides provide effective control. Mancozeb, captan, and ziram are all effective protectants against Phomopsis, but will not rescue an established infection. Strobilurin fungicides, Pristine, Abound, Flint, Quadris Top, as well as Sovran have all been shown to provide moderate control, <u>but they should not be relied upon in place of a protectant during critical times of year (3-5" of shoot growth).</u> Copper provides minimal control.

Black Rot

If the early season diseases were competing in the Olympics, Black Rot would easily claim a spot on the podium. Black rot thrives in humid climates and is prevalent in the eastern industry. Under NY conditions, berries are highly susceptible to black rot from cap fall until 3-4 weeks (Concord/Niagara) or 4-5 weeks (*V. vinifera*) later. After this point the berries begin to lose susceptibility and will become resistant/immune after an additional 2 weeks. While black rot can be spread by spores blowing in from distant infections on wild grapevines, it is most frequently started from mummified berries left by the previous year's infections, making vineyard sanitation CRITICAL for effective black rot management (see subsequent section on cultural management for more detail). Infection will spread from leaves to the fruit and can result in complete crop loss under severe conditions.

Black rot on leaves, P. McManus, University of Wisconsin-Madison

Black rot on Niagara cluster, K. Gold, Cornell University

Protectants mancozeb and ziram have been shown to provide effective control. Captan is less effective but will provide some control. Copper only provides slight control. Unlike powdery and downy mildew, the DMIs and strobilurins will generally provide strong black rot control. High efficacy products include Abound, Aprovia Top, Pristine, Quadris Top, Inspire Super, Revus Top, Luna Experience (rate dependent), Luna Sensation (rate dependent), Rhyme, Topquard EQ, Sovran, Rally, Miravis Prime, Mettle, Flint Extra, and tebuconazole. Biopesticides with high to moderate efficacy against Black Rot include Lifegard WG (high), Howler (moderate), and the combination of Regalia + Stargus (high/moderate). For more detail on these ratings were assessed, see the next section.

Recent Research

With support from the New York Wine and Grape Foundation, we established a Black Rot trial in our 20-yr-old, own-rooted Niagaras vines at the Cornell Pathology Vineyards in the 2021 season. Poor control of black rot by OMRI labeled fungicides is a major barrier to organic grape production in NY. It is our hope that by establishing this trial with a focus on biopesticides, we will help open a new consumer market for NY juice grape producers. Treatments were applied to 4-vine plots arranged in a RCBD and replicated 4 times.

Sprays were applied with a hooded boom sprayer operating at 100 psi and delivering a volume of 50 gpa at bloom and 100 gpa post-bloom. Each year of the study, Carbaryl 4L was applied twice for Japanese Beetle and Grape Berry Moth control. Disease assessments were made on 20 leaves and 20 clusters collected from the center of each plot on around Labor Day. Disease severity (percent area infected) for each leaf and cluster was estimated visually; disease incidence was calculated from this data as the percentage of leaves and clusters showing any infection.

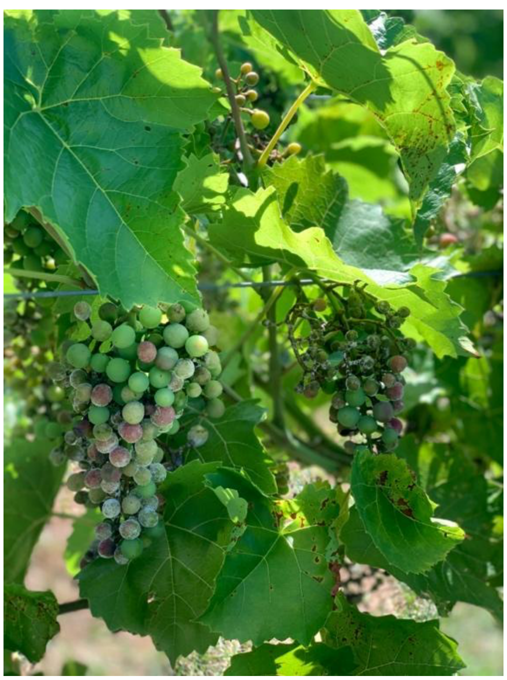
The 2021 and 2022 seasons were quite different for our black rot trials. In 2021, no commercial standards, nor any of the biopesticides, controlled leaf and cluster infection (incidence) to satisfactory levels. It was a resounding win for black rot this year. In 2021, the fungicides that showed highest control of cluster infections were Parade SC, Lifegard WG, and Oso 5SC with approximately 98.8%, 97.5%, and 100% control respectively. In 2022, fungicides made a comeback, knocking black rot down significantly. Leaf infection area (severity) was too low in the UTC for us to make meaningful evaluations, however it was a solid year for all other evaluations. Of all the treatments, Aprovia 0.83EC, Mettle 125 ME, and Lifegard WG showed the highest efficacy with cluster infection rates of 16%, 20%, and 21.3% respectively, and high control rates ranging from 78.5% to 83.8%. Overall, the 2022 study found that Aprovia 0.83EC, Mettle 125 ME, Lifegard WG, Timorex Act, Aviv, Regev, and the combo of Regalia and Stargus were the most effective treatments in controlling black rot infection in both clusters and leaves. Lifegard WG showed an exceptional performance for leaf infection control. However, some biopesticides exhibited high infection rates, highlighting the need for further research and development of these products.

Despite the seasonal variation across the 2021 and 2022 seasons, several treatments emerged as particularly effective against our resilient black rot. Amid the plethora of treatments, Aprovia 0.83EC consistently showcased notable efficiency across both seasons. Its ability to reduce cluster infection severity made it a standout performer, thereby solidifying its place as a reliable commercial standard. This product also provided the best incidence control of the included commercial standards. Biopesticides also put forth a commendable performance, with Lifegard WG demonstrating consistent efficacy in both the years and was able to control black rot incidence on leaves and clusters on par with the conventional in our study in both seasons. Despite the formidable nature of black rot, Aprovia 0.83EC, Lifegard WG, and the Regalia-Stargus combination, have consistently shown promise in mitigating the disease's impact over the 2021 and 2022 seasons. We look forward to seeing the results of year 3 Black Rot vs Fungicides battle this upcoming season!

Downy Mildew

Downy mildew is caused by an oomycete (fungal-like) pathogen and thrives in warm, humid regions. While all five of the early season grape diseases can result in significant crop loss if unmanaged, mismanaged downy mildew is the only one that can result in total vine loss. Under the right conditions, downy mildew infections can "explode" and cause premature defoliation, which at best impedes critical post-veraison ripening, and at worst makes them more susceptible to winter injury/kill. Severe downy mildew pressure in the prior season will likely result in an abundance of primary inoculum to control in the following year's early season. Early season, primary infections begin when spores spread from leaf litter on the ground to young leaves and clusters, beginning about 2-3 weeks prior to bloom. Suckers or volunteer seedlings are often the first infected because they're closest to the ground. Unfortunately, sanitation and dormant sprays have no effect on downy mildew, but early season cultural management for other diseases provides an opportunity to scout for these primary infections to see if your management to date has been effective.

Downy mildew on Chardonnay foliage, K. Gold, Cornell University



Downy mildew on Chancellor clusters, K. Gold, Cornell University

Early season downy mildew management is essential for effective season-long management. If downy mildew is mismanaged in the early season and becomes established, infections will produce secondary inoculum season-long whenever conditions become conducive, resulting in cascading late season epidemics. Secondary inoculum release is triggered by warm, humid nights with rain shortly thereafter. Without rain, most secondary inoculum will stay in place and die the next day when exposed to bright sunlight. However, spores can survive and remain infectious for several days between rainfalls if conditions remain cloudy. All *V. vinifera* clusters are highly susceptible from first shoot appearance through approximately 4-5 weeks post-bloom. Berries become resistant to direct downy mildew infection at this time, but pedicels and foliage remain susceptible long after.

Practices that encourage air circulation and speed drying time can reduce disease pressure but will not replace the need for chemical control. All systemic fungicides for downy mildew management are prone to disease resistance development and should be used in rotation within a sound, integrated pest management program. Protectants used to control Phomopsis and/or black rot early in the season, such as mancozeb and captan, will also provide good preventative control of downy mildew. Ziram provides moderate control of downy mildew but is not as effective as mancozeb and captan. Copper provides good control, but it should be noted that that copper can cause injury to the foliage at the time of season when downy mildew management is most essential (succulent leaves). Zampro, Revus, and Revus Top (the mandipropamid component) provide excellent downy mildew control, ***when resistance is not present***. However, **resistance is becoming more and more widespread- *in 2021, 70% of FLX vineyards tested positive for Frac-40 (e.g. Revus) resistance*. DO NOT RELY ON FRAC-40's *alone* for DM control during the critical control window.** See the subsequent "Recent Research," for more on the status of Frac-40 resistance in NY state. Ranman provides good control, especially when paired with Phosphorous Acid (PA) products. PA products such as Phostrol, Rampart) provide good preventative and post-infection control ("kick-back"). As a caveat, overuse of phostrol as a curative has led to reports of slippage. Phostrol should be used with caution as a curative on mild infections and NOT USED on moderate to severe infections. Ridomil remains the best fungicide ever developed for downy mildew control but is extremely prone to resistance development (and expensive), and should ***never*** be used more than once per season. Ridomil should NOT be applied to raging infections. Ridomil is most effective when applied within 4 days of initial infection, before sporulation occurs. Ridomil Gold SL has a preharvest interval (PHI) of 60 days, while Ridomil Gold Copper has a PHI of 42 days. **We do not recommend strobilurin fungicides for downy mildew control.**

Severe downy mildew on Chardonnay foliage. K. Gold, Cornell University

As a reminder, DMI fungicides (aka the Top in Revus Top) have NO EFFICACY against downy mildew and oomycetes. This is because DMI fungicides target biological components that only true fungal organisms (like powdery mildew, botrytis, and the rest of the early season pathogens) have. See my recent Grapes 101 article, "Downy Mildew is caused by an Oomycete. What's an Oomycete? Why does it matter?" in Appellation Cornell (https://grapesandwine.cals.cornell.edu/newsletters/appellation-cornell/2021-newsletters/issue-44-march-2021/oomycetes/) for more information on how oomycetes differ from true fungi and the management implications.

What about biopesticides? When considering using biopesticides for downy mildew (or any disease for that matter), it is important to remember that they act very much like a lock on a door against a thief. They will stop opportunistic, weak thieves, but determined, strong thieves can still break through with enough force. And biopesticides can't stop a thief that is already inside the house when the door is locked. Previous studies from Wayne Wilcox's program at Cornell AgriTech continued by my group found that the biopesticide LifeGard provides comparable control to standard products in moderate disease pressure years, and excellent control when used in rotation with FRAC 40 products (Zampro, Revus) in both moderate and high-pressure years. On its own, Lifegard provides moderate downy mildew incidence control and good-excellent severity control. Howler provides moderate downy mildew control on its own, and good-excellent control in rotation with conventional products. Romeo provides moderate downy mildew control. Overall, our trial findings suggest these biopesticides are particularly useful for growers pursuing low-input/biointensive management programs, or to reduce pressure on resistance prone materials via use in rotation with synthetic protectants and systemics. See the "**Biopesticides"** section for more thoughts on how to use biopesticides in your disease control program. We will continue to test new biopesticide products as they come to market to determine their efficacy on downy mildew and other important diseases.

Unique Symptoms in 2021

In the 2021 growing season, we saw some unique downy mildew symptoms that initially stumped even me, dear reader. I would like to caveat that I was quite sleep deprived at the time, given my newborn daughter was only a few weeks old. These unique symptoms were fascinating to see, and worth discussing in this year's disease control article.

On July 24, 2021, Tim Martinson emailed me about odd cluster symptoms he and Hans Walter-Peterson had heard about around the Finger Lakes (left and center left). While the clusters of affected grapes themselves did not appear to have any visible signs (a *sign* relates to physical evidence of the pathogen [like spores], unlike a *symptom*, which is the plant's reaction to infection [like wilt]), of infection, however they were starting to become shrunken, soft, and discolored. The peduncles were browning from the berry end towards the rachis (right and center right) and easy to detach from the pedicels, but there were no visible lesions. Some berries had what appeared to be secondary infection, but nothing immediately identifiable as one of our typical NY diseases.

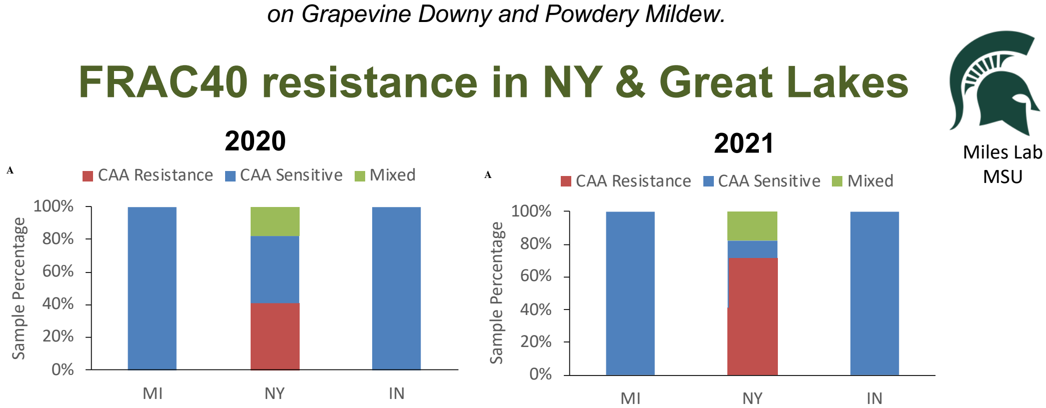
However, when examined closely under the microscope (right), we were finally able to identify fluffy, white sporulation- it was **downy mildew**. After leaving the clusters overnight in a humidity chamber, the sporulation became even more prevalent. These unique downy mildew symptoms were the result of perfectly timed infections taking place *after* the berries had become resistant, but *before* the peduncles and rachis became resistant as well. As the infections on the peduncles & rachis grew, they cut off nutrient flow to the berries, resulting in the shriveled appearance. The pathogen continued to grow into the berry from the pedicel. When we sliced open the berries and left them in a humidity chamber, sporulation occurred.

Recent Research

I'll cut right to the chase: **FRAC-40 (e.g. Revus) resistance is COMMON in NY downy mildew populations and is growing in prevalence. DO NOT RELY ON FRAC-40's *alone* for DM control during the critical control window.** In 2020, the lab received a NY Specialty Crop Block Grant to support a collaboration with Hans Walter-Peterson (Cornell Cooperative Extension) and Tim Miles (Michigan State University) to investigate the extent of FRAC-40 (aka Revus and one of the actives in Zampro) resistance in grapevine downy mildew across NY state. Resistance was first documented in Virginia in 2016. This project has provided support to evaluate new synthetic and biopesticide products for efficacy against downy mildew, survey NY vineyards for resistant DM using a new diagnostic tool developed by Miles lab graduate student Nancy Sharma, and develop resistance management extension materials. In 2020, we collected preliminary samples from 20 locations across Keuka, Seneca, and Cayuga Lakes. In 2021 and 2022 we were able to collect samples from almost 50 locations in the FLX, including juice grape varieties.

2020 and 2021 FRAC-40 Resistance Results

Sharma, N., Heger, L., Combs, D.B., Gold, K.M., and Miles, T.D. 2022. Proceedings of the 9th International Workshop on Grapevine Downy and Powdery Mildew.



FRAC 40 (Revus) resistance

- ~70% of FLX vineyards have Frac40 resistance, up from 40% in 2020
- Resistance has thus far only been detected in wine grape populations

In 2020, Nancy found that about 40% of the vineyards sampled from New York registered as **positive for Frac-40 (e.g. Revus) resistance**. **In 2021, this number increased to *70%* of vineyards testing positive for resistance. Preliminary results from 2022 testing indicate that <u>76%</u> of vineyards sampled have tested positive for resistance.** What's notable about the resistance documented in 2022 is that it was from earlier in the season (~July) than any of the previous samples, which leads us to believe that the resistance in our populations is not ephemeral and is indeed well established. Thus far, we have only detected resistance in samples collected from wine grape varieties. While these results are certainly not thrilling, they are also not surprising. You can read more about the research behind these findings in Nancy's conference paper, referenced above.

So, do I think that resistance is increasing in prevalence? Well, based on the numbers, yes, but I think its more nuanced than that. Nancy's resistance assay requires the presence of actively sporulating downy mildew to be effective, which means that there had to have been a disease breakthrough / control failure (either from resistance or lack of appropriately timed coverage) for us to sample. Control failure that results in downy mildew developing can either come from either resistance or a lack of appropriate fungicide coverage (intentional or not). In the 2020 season, most growers were still using FRAC-40 to manage DM. When we first reported FRAC-40 resistance at the end of 2020, many growers, but not all, moved away from using FRAC-40 in the 2021 and 2022 seasons. However, the rollout of our testing program was slow due to the global pandemic. Growers who had not yet moved away from FRAC-40 to manage DM *and* whose vineyards had yet undetected, but present, resistance, would therefore be more likely to have breakthrough downy mildew for us to sample during the 2021 and 2022 seasons, which would artificially inflate resistance rates. So, what is my gut estimate on the prevalence of resistance? Likely somewhere between the 2020 (~40%) and 2021 (~70%) results, perhaps closer to 50/50. Regardless, below are some guidelines on how to move forward with managing FRAC-40 resistant downy mildew, whether you have officially tested positive or not.

Managing FRAC-40 Resistant Downy Mildew

1) Start your season with at least two rounds of broad-spectrum fungicide (such as mancozeb) before moving to site specific fungicides.
2) **Do not rely on FRAC-40 chemistries *alone* for DM control during the critical immediate pre-bloom to immediate post-bloom control period.**
3) When possible, **double up your DM actives by tank mixing**. For example, half of Zampro is still effective against FRAC-40 resistant downy mildew, but it is *very* resistant prone (that's why it was sold paired with Revus in the first place). Tank mixing with another DM product will help protect the still-effective active ingredient remaining in Zampro as well as help prevent against "escapes."
4) Be aggressive in your early season control program when pressure is lowest to prevent infections from establishing. Many aspects of resistance management come down to simple numbers games: if there is abundant disease, there are more spores. If there are more spores, it is more likely that a resistant individual is present.
5) Remember your cultural control! Training and pruning improve both spray penetration and air flow.

Powdery Mildew

Powdery mildew on foliage, P. McManus, University of Wisconsin-Madison

Powdery mildew is, without a doubt, the most important fungal disease of grapevine worldwide. Uncontrolled powdery mildew can destroy infected clusters and cause "diffuse" cluster infections that increase susceptibility to bunch rots. Leaf infections limit photosynthesis and reduce fruit quality, vine growth, and winter hardiness. In general, *V. vinifera* are most susceptible to powdery mildew infections, hybrids are intermediate, and natives least. Humidity and shade both promote disease development because powdery mildew is inhibited by sunlight, specifically ultraviolet light. Maintaining an open canopy that allows sunlight to penetrate into the canopy will reduce disease pressure, but will not replace the need for chemical control. Unlike downy mildew, rainfall is not necessary to spread powdery mildew. However, research has shown that powdery mildew disease severity is twice as great at a relative humidity (RH) of 80% versus a RH of 40%. The risk of rapid powdery mildew development increases in vineyard sites and canopies with poor air circulation and increased microclimate humidity (high shoot density), and seasons with frequent precipitation.

Powdery Mildew on foliage and clusters, W. Wilcox, Cornell University

Vinifera and mildew-susceptible hybrid clusters are extremely susceptible to powdery mildew infections from immediate pre-bloom until 2 weeks after fruit set. Fungicides applied during this critical period carry a disproportionate weight with respect to fruit infection for the entire season. Berries become nearly immune to new infections about 4 weeks after bloom (ontogenic resistance, discovered by Cornell's David Gadoury). Thus, the period from immediate pre-bloom to 2 weeks after fruit set is an opportunity to use the best materials at relatively close intervals, and to get the most bang for your buck, so to speak, with respect to fruit disease suppression.

It is important to note that diffuse and inconspicuous powdery mildew infections on the berries can occur if fungicide protection is terminated before berry resistance is fully expressed (between weeks 3 and 4 post-bloom). Powdery mildew colonies create small wounds in berry tissue, which can increase susceptibility to Botrytis and other fruit rots after veraison and at harvest. Diligent powdery mildew control won't guarantee control of either of those things, but it does eliminate a pathway for them to get started. Concord berries become highly resistant about 2-3 weeks after flowering, though the rachis remains susceptible until late summer.

Early powdery mildew infections on fruitlets can cascade quickly into total crop loss under conducive conditions. Keeping leaves virtually free of powdery mildew going into pre-bloom helps assure there will be minimal inoculum during the critical immediate pre-bloom through early post-bloom period when susceptibility is highest. Wayne Wilcox often referred to powdery mildew as a "compound interest" disease with good reason. This is because the initial inoculum (in his analogy, the deposit) is directly proportional to the amount of disease that developed in the prior season. This means that disease pressure will be higher (and early season control will be most critical) in vineyards where control lapsed in the prior season, as opposed to vineyards that remained fairly clean through September. Thus, early-season sprays are critical on susceptible varieties in order to avoid cascading epidemics in the later season, and sprays during the first few weeks of shoot growth will be particularly important in blocks with late season powdery mildew in the prior year.

Powdery mildew on cane and clusters, K. Gold, Cornell University

Unfortunately, fungicides that provide preventative control of the other early season diseases such as mancozeb, captan, and ziram DO NOT provide effective control of powdery mildew. Fortunately, elemental sulfur provides highly effective preventative and curative powdery mildew control with low risk of disease resistance development. Sulfur will provide excellent post-infection control when applied up through the time that young colonies start to become obvious. Post-infection sprays applied to heavily-diseased tissues are much less effective, so sulfur should not be relied upon for eradication of existing PM colonies. Rainfall will wash off sulfur, leaving new shoot growth unprotected. Sulfur must be applied frequently (e.g. ~7 day intervals) to provide effective season-long control. Some grape varieties, including Concord, are susceptible to foliar injury from sulfur, and sulfur applications should be avoided in these varieties.

Powdery mildew is unique in that the causal organism lives entirely on the surface of infected tissues. This is why powdery mildew can be surprisingly well controlled by a number of alternative spray materials. Oils, bicarbonate and monopotassium phosphate salts, hydrogen peroxide, various plant extracts and microbial fermentation products that do very little on other grape disease-causing fungi that live their lives within leaf tissue frequently provide good powdery mildew control. These products work by direct physical contact with the fungus, meaning they are *only* as effective as the spray coverage you provide. Additionally, they work primarily in a post-infection curative manner by killing the fungus *immediately* after application. At best, these products will provide modest (such as JMS stylet oil) or no residual protective activity against spores that land on the vine after application. They therefore need frequent reapplication, or need to be tank-mixed with a protectant.

Tank mixes consisting of curative, post-infection powdery mildew materials with a protectant can help control existing infections, especially at critical times when grape tissue is most susceptible. All systemic fungicides for powdery mildew management are prone to disease resistance development and should be used in rotation within a sound, integrated pest management program. Repeated use of any single chemistry will eventually result in resistant strains of powdery mildew that can no longer be controlled with applications of fungicides within that chemistry. At least two, and preferably more, FRAC groups should be used on a rotational basis to avoid or delay the onset of resistance. FRAC 11 (strobilurin) resistance is becoming more and more of a problem across the US, and the eastern industry is no exception. Therefore, **DMI and strobilurin fungicides should NOT be relied upon *alone* for powdery mildew control.** Pre-mixed strobilurin fungicides such as Pristine (strobilurin + SDHI), Quadris Top, Topguard EQ, and Luna Sensation provide good powdery mildew control. SDHI fungicides and pre-mixes such as Endura, Aprovia/Aprovia Top, Pristine, Luna Experience, Rally, and Miravis Prime provide good to excellent control. Vivando, Prolivo, Sovran, Quintec, and Gatten all provide excellent control. Pre-bloom applications of stylet oil can provide good to strong powdery mildew control, but can cause leaf injury on certain varieties, or burn when over used. The NY/PA Grape Pest Management guideline provides useful tables of sensitivity ratings by variety: https://cropandpestguides.cce.cornell.edu/

What about biopesticides? As stated in the downy mildew section, biopesticides act like a lock on a door against a thief. They will stop opportunistic, weak thieves, but determined, strong thieves can still break through with enough force. And they can't stop a thief that is already inside the house when the door is locked. An important exception to this is Stylet Oil, which is an excellent powdery mildew eradicant, in fact probably the only decent one we have. There are several biopesticides available that are labeled for powdery mildew control. Regalia provides moderate to good control. When Regalia is paired with Stargus it provides good control. Howlery, Romeo, Oso, and Ph-D (polyoxin-D) provide moderate control. Double Nickel provides moderate control.

Late studies from the Wilcox program continued by my program found that when used on its own, the biopesticide LifeGard provides good disease severity control and moderate disease incidence control. In a high-pressure year, it provided slight control for both incidence and severity. In mild to moderate pressure years, Lifegard provided excellent severity control and good/excellent incidence control when used in rotation with synthetic fungicides. In high pressure years, these rotations provided moderate incidence control and good severity control. Overall, our trial findings suggest these biopesticides are particularly useful for growers pursuing low-input/biointensive management programs, or to reduce pressure on resistance prone materials via use in rotation with synthetic protectants and systemics. See the "**Biopesticides"** section for more thoughts on how to use biopesticides in your disease control program.

Recent Research

UV Disease Control. In 2020, Cornell Grape Pathology collaborated with David Gadoury to test the feasibility and reliability of autonomous robots (built by Saga Robotics) to deliver nighttime doses of ultraviolet light (UVC) for powdery mildew control in our Chardonnay pathology vineyard. UVC applications were initiated approximately 30 minutes after sunset, and were completed within 2 hrs. Nighttime UVC applied twice weekly by the robots at 200 J/m2 provided excellent suppression of powdery mildew on leaves and fruit under severe disease pressure. Observed powdery mildew severity under UVC treatment was 2.8% on foliage and 1.2% on fruit clusters at veraison, which was comparable to suppression provided by commercial standards in our powdery mildew fungicide efficacy study next door. UVC did not provide downy mildew control. For more on our use of UV light for disease control, see the Sour Rot recent research section.

UVC robot in action at Cornell Pathology Vineyards, D. Gadoury, Cornell University

VitisGen3 Trials. In May 2023, we (here I use the royal "we," as Dave Combs, our Field Research Manager, did all the hard work!) planted two new vineyards as part of the recently funded USDA NIFA SCRI VitisGen3 to conduct VitisGen's first ever field trials to design low-input disease management programs for their new, powdery mildew resistant varieties. We will be evaluating how spray programs driven by powdery mildew epidemiology controls disease in moderately disease resistant NY06 and assessing the benefit of stacked resistance genes in 6 variety fungicide trial. Within these trials we will be focusing on both conventional and biopesticides, seeking to optimize biopesticide use by variety and phenology.

Anthracnose

Anthracnose isn't the worst of the early season diseases by any means, but when it's a problem, it's a problem. Historically, anthracnose was only considered to be an issue on Vidal, Reliance, and seedless varieties, but outbreaks have become more common in recent years in New York with the increasing prevalence of cold-hardy varieties. Cold hardy varieties with *V. riparia* in their background such as Marquette (particularly susceptible), Frontenac, La Crescent, Edelweiss, Esprit, Brianna, St. Pepin, and Swenson White tend to be susceptible. Generally speaking, this is a rarer disease primarily associated with wet, humid conditions around bloom on susceptible varieties. All

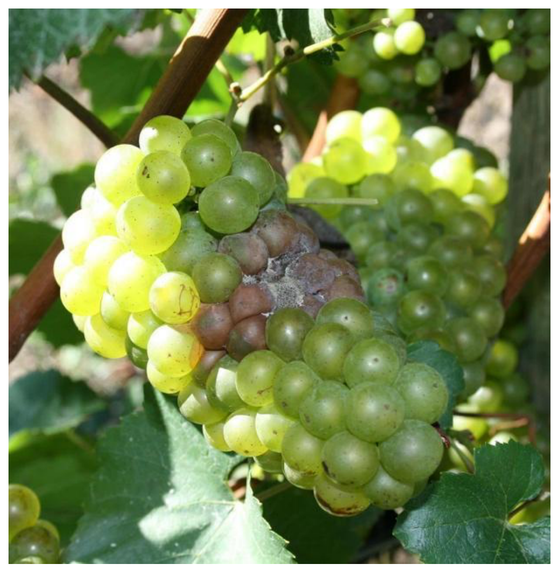
Anthracnose on clusters, P. McManus, University of Wisconsin-Madison succulent parts of the plant, including fruit stems, leaves, petioles, tendrils, young shoots, and berries, can be attacked, but lesions on shoots and berries are most common and distinctive. A liquid lime sulfur dormant spray is the most reliable and effective management option for established, difficult to control populations. Early season sprays of mancozeb, captan, or ziram targeting Phomopsis have been noted to provide significant control of anthracnose despite not being listed on the label. Any control received should be considered a nice bonus, and these products should not specifically be sprayed for anthracnose control. Rally, Mettle, Pristine, and Revus Top are all labeled for anthracnose control, and most DMI or sterol inhibiting fungicides have shown adequate control.

Late Season Grape Diseases

Management in the mid-late season has two primary foci: keeping powdery mildew and downy mildew under control on the canopy to prevent primary inoculum build up (and late season defoliation) and controlling late season bunch rots on the clusters. This section will introduce the two major late season rots of NY grapes, their management, and relevant recent research.

Botrytis Bunch Rot

Botrytis bunch rot, or grey mold, is caused by the necrotrophic fungus *Botrytis cinerea* and is one of the most important grape diseases worldwide. Botrytis is often called a “weak” pathogen in that it prefers to opportunistically attack highly succulent, dead, injured, damaged, or senescing tissues rather than make its own way in the world, but don’t for a second think that means the damage it can cause when left to its own devices is anything but extensive. Botrytis thrives in humid, still air, hence the value of cultural practices that promote airflow in the fruit zone. Additionally, there is a well-established link between berry injury, such as that caused by grape berry moth larvae, powdery mildew scarring, or excessive rain, and Botrytis attack. For more on cultural practices that can reduce botrytis, see the “Cultural Control,” section of this article.



Botrytis bunch rot, P. Skinkis, Oregon State University

Senescing tissues such as blossom parts and aborted berries, as well as ripening berries after veraison, are important targets for the Botrytis fungus. Though Botrytis can only start to cause disease once berries begin to ripen, the fungus can gain entry to young fruit around bloom resulting in latent infections. These latent infections are the result of the fungus infecting senescing blossom parts stuck within the cluster, AKA “bloom trash.” Tight clustered varieties that retain more bloom trash are thus at higher risk of acquiring latent infections. Latent infections initiated at bloom will remain dormant while berries are green until environmental “activation.”

In most seasons, the majority of latent infections remain inactive through harvest. The factors that trigger latent infection activation are not fully understood, but appear to be related to high nitrogen content and high atmospheric relative humidity (RH). High humidity and physical damage during the post-veraison period can promote activation as well. The Wilcox Lab found that latent infections occurring during bloom and post-bloom resulted in relatively few rotten berries in and of themselves, BUT they are capable of acting as “primary” infections, providing a foothold for the pathogen to take off. This can result in in damaging levels of secondary spread when latent infections activate under disease-conducive pre-harvest conditions.

The risk posed by latent infections should not be ignored but is overall less significant than the risk posed by veraison and post-veraison infection. Veraison and post-veraison infections are by far the most damaging and costly. Veraison and post-veraison infections do not undergo the latent period, and can immediately cause symptoms on berries. The Wilcox Lab at Cornell AgriTech found that the highest levels of at-harvest disease results from infections established at veraison, consistent with Botrytis’ known preference to colonize senescing tissues.

Conditions favoring disease development include not only climatic factors, like humid and still air, but various vine factors, such as high nitrogen levels and compact clusters. Cluster compactness is extremely influential (as any grower of Vignoles can tell you), since the fungus can spread through tight clusters from just a single initial berry infection via berry-to-berry contact. Pre-harvest spread may be increased with high nitrogen content of foliage and berries (high soil nitrogen and or foliar urea applications). Thus, you’ll want to be more diligent with Botrytis scouting and management if you apply post-veraison nitrogen. If you are growing a tight clustered variety with a history of Botrytis bunch rot issues, you may want to avoid excessive levels of nitrogen application (and pre-harvest irrigation where that is practiced).

Now considering management, it’s important to remember that a good spray program for Botrytis can only go so far. It’s absolutely critical to set your expensive fungicides up for success with diligent cultural control (see “cultural control” for more details). Fostering an open canopy with fruit zone exposure promotes rapid drying, which in turn lessens Botrytis risk. It’s always a good idea to make sure your shoots are well tucked and spaced within the catch wires, and summer pruning has removed shoots ends that may block sprays from thoroughly penetrating the fruit zone, just before you make each Botrytis fungicide application. Pre-veraison sprays (bloom and pre-closure) are to limit latent infections while veraison and post-veraison sprays are to protect the berries when they are most susceptible. In varieties with very compact clusters, the pre-closure spray may be extremely important, as it may be your last opportunity to get protective fungicides onto the interior surface of clusters where these latent infections are hanging out. The post-veraison spray (generally 2-3 weeks after veraison) will be important in seasons when the weather is particularly wet and humid.

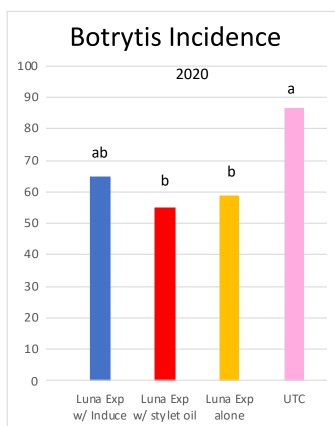
Seven FRAC groups are labeled for Botrytis control, but primarily SDHIs (FRAC 7) and QOIs (FRAC 11) are used. **All fungicides labeled for Botrytis control have high risk of resistance development. Do not make more than two applications per season of a given FRAC code and never apply the same FRAC group twice in a row.** It is good practice to ALWAYS rotate to unrelated fungicides between SDHI and QOI applications. Endura (high rate), Pristine (high rate), Vanguard, Elevate, Switch, Rovral/Meteor, Luna Sensation, Scala, and Flint Extra (high rate) all provide excellent Botrytis control. Inspire Super, Luna Experience (high rate), Intuity, and Miravis Prime provide good control. ProBlad Verde (formerly known as Fracture) and Botector provide moderate to good control. Double Nickel, Sovran, Oso, and Ph-D provide moderate control. All fungicides registered for Botrytis control provide excellent protective activity on the berry surface. Elevate, Vanguard, and Scala provide good protective activity within the berries and good curative activity against latent infections. It's likely that Switch provides this to some extent as well, given that it contains the same active as Vanguard (just at a lower amount), but this was not tested by the Wilcox program. It should be noted that the level of curative activity against latent infection provided by veraison and post-veraison sprays of these products under field conditions does NOT replace the need for bloom and closure applications when conditions are particularly disease conducive at bloom.

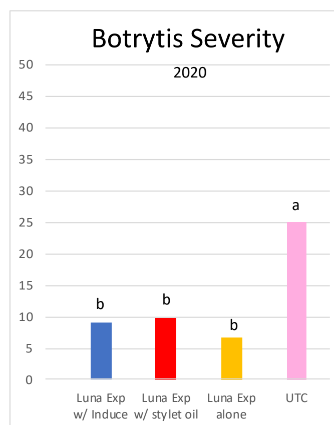
Recent Research

Do adjuvants affect Botrytis disease control? Growers have longer wondered whether adjuvants had an impact on Botrytis fungicide efficacy. Despite becoming an emeritus professor in 2018, to the surprise of absolutely no one who knows him, my predecessor Wayne Wilcox couldn't stay out of the vineyards and decided to investigate this with a controlled experiment within our seasonal Botrytis efficacy trial. This work was continued by my program in 2020. To evaluate whether adjuvant usage and type can impact Botrytis disease control, we did a series of evaluations with Luna Experience as our base product applied at standard rates and timings:

1) Untreated control
2) Luna Experience alone
3) Luna Experience with stylet oil
4) Luna Experience with Induce

We evaluated cluster incidence and severity following our standard protocol at harvest time- included here are our 2020 season results. While we did see some variation year over year, our preliminary findings indicate that there was **no significant difference** between any of the experimental treatments in the 2020 season and across three years of study.





Botrytis Incidence and Botrytis severity in experimental vineyards under different treatment conditions.

Sour Rot


Sour rot, K. Gold, Cornell University

Sour rot is caused by a four-way interaction amongst naturally occurring microbes (acetic acid bacteria + yeasts), *Drosophila* flies, and fruit wounding and is of growing concern to NY grape production. Under the right conditions, sour rot can cause major economic damage to wine grapes in NY and elsewhere, especially negatively impacting high value cultivars, as occurred in 2018 and 2022. In bad years, sour rot disease can present a significant challenge to producing high quality grapes for wine production in all regions of NY where grapes are grown. The characteristic visual symptom of sour rot is a tan to occasionally reddish discoloration of the rotting berries, which eventually lose their integrity and begin to decompose. Sour rot can be distinguished from Botrytis bunch rot by the lack of moldy growth on and between berries. Whereas various molds, including botrytis, are often found on sour-rotted clusters, these organisms are not necessary for sour rot to develop. One additional group of organisms characteristically associated with sour-rotted clusters, which are highly visible and appear to be an important if not essential component of the disease, are Drosophila "fruit flies" or "vinegar flies." Sour rot is called sour rot for a reason, and earns its name from the pungent vinegar smell the rotting clusters give off. Oftentimes you can smell sour rot in the vineyard before you see it.

Pioneering research by Megan Hall, Wayne Wilcox, and Greg Loeb unveiled the unique, multitrophic nature of this peculiar rot. In order to get sour rot, you need a wounded grape, a yeast to ferment the sugars and generate ethanol, acetic acid bacteria to convert that ethanol into vinegar, and fruit flies. Yeasts and acetic acid bacteria occur naturally on and in grapes, healthy or otherwise, and there is in fact no meaningful difference between the microbiome of healthy berries and sour-rotted, meaning that the culprits are naturally occurring. It appears as though these endemic microbes only turn antagonistic and develop into sour rot when the berry is both wounded <u>and</u> exposed to fruit flies. Wounds are important for sour rot development as they expose a sugary carbon food source for nearby yeast and bacteria causing them to increase in abundance, create an aerobic environment ideal for converting ethanol to acetic acid, and release volatiles that attract the flies. Wounds can be caused by a number of agents (and is the subject of ongoing collaborative research between myself, Greg Loeb, and his MS student, Rekha Bhandari), but most frequently by the grape itself. Riesling, Pinot Noir, Sauvignon Blanc, Chardonnay, and Vignoles are especially at risk for developing sour rot because of their tight cluster architecture. As the clusters grow, wounds are formed as the berries rub up against each other and expand. Loose clustered varieties are thus less prone to sour rot.

The final component of sour rot are fruit flies. It's clear that they are necessary for disease development, but their exact role, be it enzyme secretion or something else, is not yet known. Preliminary research conducted by M. Hall while she was at the University of Missouri (now an independent viticultural consultant on the west coast) showed that larval fruit flies can cause sour rot at the same rate as adult fruit flies on wounded and inoculated grapes, but it is yet unknown the mechanism behind this phenomenon.

Now considering management, the most important things to keep in mind is that 1) disease is initiated once rains occur after berries reach approximately 15° Brix and 2) warm temperatures (significant periods of time in the upper 60's and above) are much more problematic than cooler temperatures (credit owed to Wendy McFadden-Smith for both discoveries). Warm nights should definitely trigger alarm bells for sour rot scouting. Disease develops rapidly between 68-77°F and needs at minimum 60°F and rain conditions to get started (in *vinifera* vineyards at least). Therefore, lots of rain can mean lots of disease, as we saw in 2018, and very little rain can mean very little disease, as we saw in 2020. Leaf thinning and good canopy management will keep things from getting worse than they would otherwise. And most importantly, vineyard scouting at critical times of year. It's much easier to keep things down to a dull roar if you address a disease outbreak as soon as you see it (BEFORE you smell it) rather than waiting for it to explode.

Sour rot, arrows point to fruit flies. M. Hall, Cornell University at time of photograph.

In terms of chemical management, the current best practice recommendation is to use a combination of insecticide and anti-microbial (Oxidate 2.0) weekly through harvest once you start seeing the flies but before you smell the rot, starting around approximately 12-13 Brix but depending on the weather conditions that season. If you wait until you smell the rot to start spraying, your weekly sprays will only keep disease at the level at which it first appeared. Spraying weekly will NOT get you more control than 1-2 combo sprays *if and only if* you wait to start spraying until you see symptoms. The downside to the recommended weekly spray program this is that it is costly and has led to the development of resistant fruit fly populations. If you choose to follow this route, ROTATE YOUR INSECTICIDES!! Spraying the same active ingredient weekly is a surefire way to build yourself a super-resistant population of fruit flies that will be a nightmare to control. This has already been documented in the Finger Lakes by Jeff Scott, Greg Loeb, and Hans Walter-Peterson. Avoid building resistant populations by rotating your active ingredients! Emerging research on spray timing by Greg Loeb and myself is helping to refine the current best practice recommendation and will be discussed in the next section.

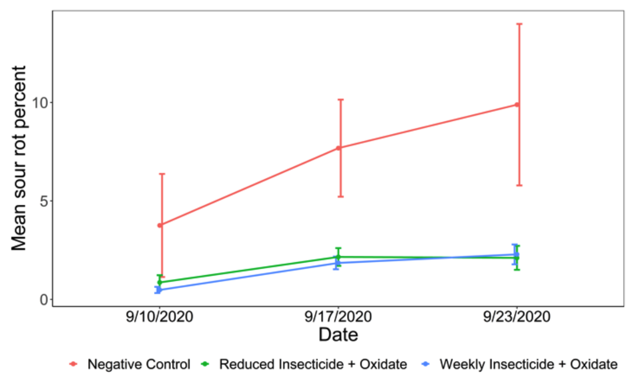
Recent Research

Refining Spray Timing.

Recent research from the Loeb and Scott entomology labs at Cornell University have documented wide-spread levels of resistance in NY populations of *Drosophila melanogaster* to three out of the four major classes of insecticides (pyrethroids, organophosphates, neonicotinoids) labeled for use against *Drosophila* in grapes. That is not to say that these materials are not providing some protection under field conditions, but there is a serious risk for control failures and it behooves the industry to apply insecticides only when necessary. In 2020, Greg Loeb and I decided to explore whether weekly combination pesticide applications (insecticides targeting *Drosophila* and surface sterilant targeting microorganisms) are truly necessary to achieve adequate control.

To address this, we conducted a timing experiment in a research block of Vignoles (highly susceptible to sour rot) located at Cornell AgriTech where we established the following treatments:

1) No insecticides or microbial pesticide
2) Weekly applications of insecticide plus oxidate 2.0 starting at about 15 Brix (industry standard)
3) Two applications of insecticide + oxidate; one at around 15 Brix, and near harvest (around 21 Brix).



Graph showing sour rot prevalence by percent in three test populations.

We evaluated the efficacy of the treatments by 1) monitoring abundance of Drosophila on clear sticky cards, 2) rearing adult flies from a subset of fruit collected near harvest, and 3) assessing incidence and severity of sour rot on several dates approaching harvest. We found greater numbers of Drosophila species on sticky cards and from rearing flies from berries between control plots (no sprays) and the other two treatments but no differences between weekly sprays (4 sprays) and 2 sprays (15 Brix and near harvest). Similarly, no difference was observed in sour rot severity between the weekly and start and near harvest treatments but both treatments had reduced sour rot compared to control (Figure 1). From these results we conclude that two pesticide applications may be as effective at controlling sour rot as four, thereby reducing selection for insecticide resistance. As a caveat, environmental conditions during late season in 2020 were not conducive to sour rot development.

2021 could not have been a more different year for this study. 2021 was an *incredibly* conducive year for sour rot. This is reflected in higher sour rot severity in our 2021 trial relative to 2020 in our research planting. In 2021, we established additional treatments in the same Vignoles research planting to better assess the impact of the number of sprays and the timing when sprays are initiated. The treatments were as follows:

1) unsprayed control

2) conventional weekly control (initiate insecticide + Oxidate treatments at 15 Brix and apply weekly until near harvest
3) Early and late sprays, one at 15 Brix and second near harvest
4) Early and late sprays, start at 12 Brix
5) initiating weekly sprays at first sign of sour rot symptoms on fruit within research plots.

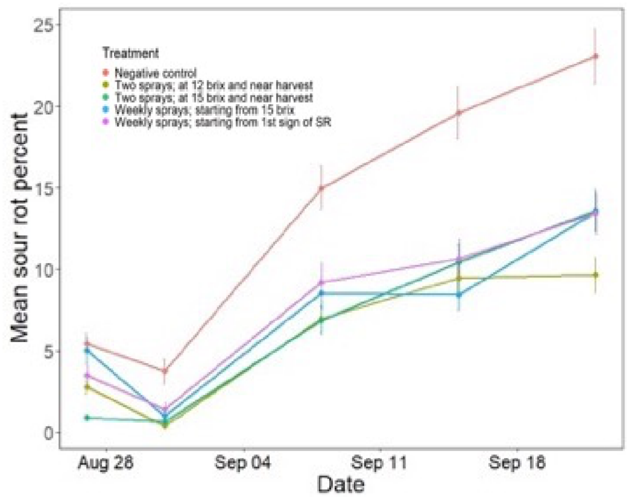


Figure 2. Mean percent sour rot on clusters, 2021 timing experiment.

Each plot was comprised of 10 to 12 vines, replicated five times in a completely randomized block design for a total of 25 plots. Incidence and severity of sour rot on 40 clusters per plot was rated twice per week starting after veraison until near harvest. Presence of Drosophila flies was assessed weekly using two monitoring methods: two transparent sticky cards placed within the canopy of each plot and a single deli cup trap baited with a Scentry lure in each plot. The overall results from the 2021 trial are consistent with 2020 in that we observed that all the different treatments with varying number and timing of pesticide applications had significantly reduced sour rot severity relative to the untreated control however, we did not observe any difference between two sprays and four sprays nor between initiating treatments at 12 Brix versus 15 Brix.

There is a trend from 2021 suggesting that initiating sprays at the first sign of sour rot, which occurred at around 12 Brix, may provide somewhat better results than starting at 15 Brix, but this needs further exploration. These preliminary results show there's reason to believe two pesticide applications may be just as effective at controlling sour rot as four.

Insect Damage and Sour Rot
Below is an excerpt from Rekha Bhandari's excellent Masters Thesis elucidating the role of berry injuries and *Drosophila* vinegar flies in sour rot etiology (text amendments by me). In short, she found that berry injury increases sour rot development, but for the most part, *only when the fruit flies are present.*

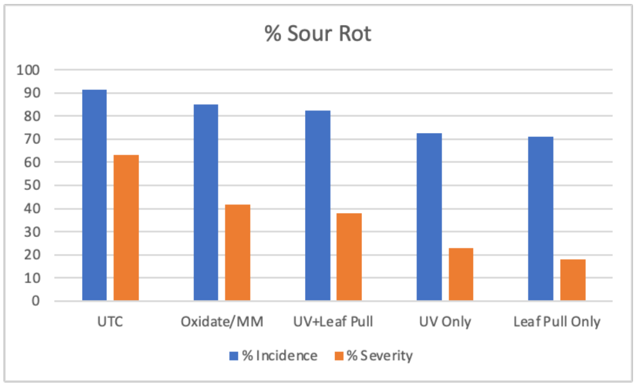
> Sour rot in grape clusters was studied to experimentally quantify the role of berry injury inflicted by different agents such as grape berry moth larvae, mechanical damage, and yellowjackets in the presence or absence of Drosophila fruit flies (D. melanogaster) on disease severity. Our experiment showed **higher sour rot percentage in response to all the injury treatments, especially when *D. melanogaster* was present, except in the negative control and grape berry moth treatments in both years (2021 and 2022).** Our results are consistent to

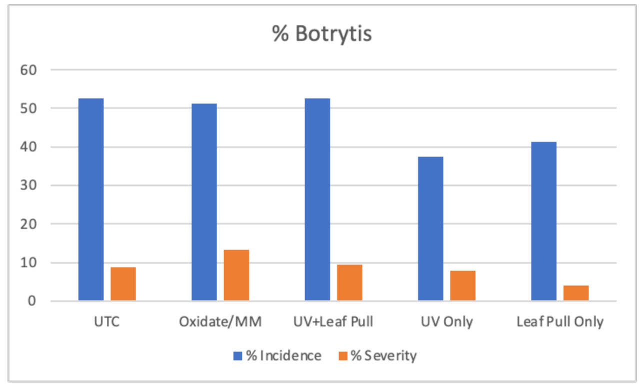
other findings (Barata, Santos, et al. 2012b, Hall, Loeb, Cadle-Davidson, et al. 2018), where sour rot severity in the absence of Drosophila was significantly less compared to when Drosophila was present. The disintegration of berries and oxidative fermentation process associated with sour rot is critical to fully develop symptoms and the full expression of sour rot symptoms is dependent on the presence of vinegar flies, especially larvae. Thus, **in the absence of D. melanogaster larvae, it is likely that the injuries caused by various agents will start to heal thereby disrupting further berry infection by sour rot associated microbes.**

This study showed that **berry injury facilitates an increase in sour rot severity, mainly in the presence of *D. melanogaster*.** Damage from bird pecks, insect feeding, and pressure from expanding berries can create openings in the berry cuticle thereby providing access to vinegar flies. Drosophila can vector sour rot associated microbes and the activity of larvae likely enhances microbial proliferation and sour rot symptoms. Our results **emphasize the importance of managing injuries in grape clusters to reduce the likelihood of severe sour rot.** Our study highlights the role of injuries by other agents in the vineyard, such as yellowjackets, in sour rot etiology. Several species of yellowjackets capable of injuring intact berries were observed in commercial vineyards in late summer in the Finger Lakes. These findings highlight the need to better understand the potential role yellowjackets play in vectoring sour rot and the possible need for their management. Overall, these results reinforce the importance of managing injuries and injury causing agents in vineyards, potentially through adopting sustainable strategies such as thickening of berry cuticles, behavioral manipulation of injury agents and physiological manipulation of plant traits through breeding techniques to prevent berry cracks.

UVC for Sour Rot control

In 2022 we expanded our UV-C trials to evaluate potential for sour rot control. We wanted to test whether UV-C applications, either alone or in combination with leaf-pulling, can provide comparable disease control to commercial pesticides. This experiment was conducted in a planting of top-wire cordon-trained, 22 yr. old, own-rooted Vignoles located on a research farm near Geneva, NY. Treatments were applied to 20-vine plots arranged in a RCBD and replicated 4 times. Ultraviolet light (UV-C) was applied with a custom over-the-row apparatus designed to deliver 200 joules/meter^2 and comparison fungicide/insecticide sprays were applied with a hooded boom sprayer operating at 100 psi and delivering a volume of 50 gpa at bloom and 100 gpa post-bloom. For the leaf pulling-only treatment, leaves were removed during early bloom on 13 Jun. Fungicide and UV-C light applications were made on 17 Aug, 24 Aug, 31 Aug and 8 Sep. Disease assessments were made on 20 clusters collected from the center of each plot on 12 Sep. Disease severity (percent area infected) for each cluster was estimated visually and disease incidence was calculated as the percentage of clusters showing any infection.





This trial produced fascinating results. Oxidate/Mustang Maxx applications did not provide any botrytis or sour rot control, and botrytis cluster severity was highest in this treatment - even surpassing the untreated control. UV-C and leaf pulling in combination had no significant effect on incidence or severity for either disease. However, UV-C without leaf pulling and leaf pulling in the absence of UV-C both reduced sour rot incidence *and* severity. Although these two treatments also reduced incidence and severity of botrytis infections, the difference was not significant compared to the untreated control. These preliminary results suggest that leaf pulling just once, at the early bloom stage, may offer better sour rot control than four post-veraison pesticide applications. In addition, four post-veraison applications of UV-C may offer comparable control to leaf pulling at early bloom. The fact that the combined leaf pulling/UV-C treatment had no significant effect on disease is puzzling, and we will investigate this further in 2023. Stay tuned for updates!

Cultural Control

A strong disease management program begins with cultural control. Diligent cultural management will ensure that your fungicide program is set up for success from the outset. Pruning, training, and sanitation are your first line of defense against all five early season grape diseases regardless of whether your operation is conventional, organic, or biodynamic.

Pruning

Anthracnose, Phomopsis, and powdery mildew all overwinter in the cane bark and release spores with the spring rain that can infect susceptible early growth tissue. Early season pruning can help reduce initial inoculum levels for these diseases. All prunings should be chopped, shredded, and/or destroyed to remove bark and pathogen. Ideally, prunings should be removed from the vineyard, though this practice can be costly. If you are pursuing low-input management, you might want to consider total removal if you have had persistent problems with cane-overwintering diseases. Summer pruning and cluster zone leaf removal will help significantly with Botrytis bunch rot management by helping your expensive fungicides penetrate to the clusters where they can do their job most effectively.

Training

Canopy management can significantly aid in early season disease control. Any practice that opens the canopy to improve air circulation and reduce drying time of susceptible tissue will broadly reduce disease incidence and severity. For powdery mildew, canopy management practices such as utilizing a VSP training system or vertical canopy division, shoot thinning, and basal leaf removal at fruit set can significantly reduce fruit disease severity. Broadly, any practice that increases sunlight exposure on leaves or fruit will reduce the severity of powdery mildew on those tissues, independent of spray coverage. Additionally, training to improve airflow will have the added benefit of improving fungicide penetration. When this improved spray coverage factor is considered, the benefit of canopy management for powdery mildew control is not only compounded, but extended to other diseases as well. Training system can also impact bunch rot severity. Justine Vanden Heuvel and Wayne Wilcox of Cornell University found that top wire systems tend to foster more bunch rot than VSP (20% more), and using a VSP system in combination with shoot thinning and sanitation (rachis removal) resulted in over 50% less bunch rot than a top wire system with no cultural practices.

Sanitation

Sanitation is essential for effective black rot and Phomopsis management, and will improve season long anthracnose and powdery mildew management. Black rot overwinters in mummified fruit ("mummies") in the vine and on the ground. These mummies will release spores with the spring rain once temperatures become conducive. It is critical to remove mummies from the canopy, and ideal to remove from the vineyard entirely, though simply dropping them to the ground has been shown to dramatically reduce spore discharge. Why take the time to remove mummies from the canopy? Canopy mummies will produce 10-20x more spores than mummies on the ground, and will continue to do so beginning from bud break through version. The spores they produce will "rain down" and hit the most susceptible, young tissue. Ground mummies are less of a concern than canopy mummies because they decompose much faster and will not produce spores after bloom. The spores that they do produce are less likely to be splashed up onto the trellis and onto susceptible young tissue than canopy mummies. The exception to this is if the weather has been dry, then ground mummies will remain an inoculum source for longer. Dropping mummies to the ground (but not right below the vines!) is better than leaving them hanging in the trellis if you cannot remove them from the vineyard entirely. If you had a significant black rot problem in the prior season and/or are pursuing low input management, consider taking the time to remove ground mummies in addition to your canopy mummies. <u>Removal of black rot mummies via early season sanitation is ESSENTIAL for all growers pursuing organic/biodynamic/low input management.</u>

Sanitation is also important for bunch rot management. For Botrytis bunch rot, removing or destroying vineyard debris such as old cluster stems (rachis) which serve as a major source of overwintering inoculum, is useful and worth employing to whatever extent is practical. For sour rot, remove all infected fruit from the vineyard, don't drop them to the vineyard floor where they can continue to attract disease inducing flies and other wound-causers.

Leaf Removal and Shoot Thinning

Leaf removal and other good canopy management practices that foster airflow pay dividends when it comes to reducing sour and other bunch rots at the end of the season. Botrytis in particular thrives in high humidity and still air. Fostering good airflow has been shown to help reduce both Botrytis bunch rot and sour rot severity both by creating a less conducive environment for disease, and by increasing fungicide penetration to the target cluster zone study. In both VSP and top wire systems, shoot thinning has been shown to reduce Botrytis severity. A combination practice of shoot thinning plus rachis removal (sanitation) was found to reduce Botrytis severity by over 40% compared to the untreated check in VSP systems.

Designing a Robust Spray Program

The overall goal of your program should be 1) simultaneous control of the most important diseases, 2) fungicide resistance management, and 3) economic sustainability. Diversification is key-an effective spray program will include BOTH protectants and post-infection materials, as well as BOTH contact and systemic materials. The four most critical sprays for early season disease management for downy mildew, powdery mildew, and black rot are immediate pre-bloom, bloom, 1-2 weeks post-bloom, and pea-sized fruits. As a rule of thumb for *V. vinifera*, cover should be maintained from 4” shoots through pea-sized fruits and thereafter whenever weather is wet/humid. For Concord, after the 1-5” Phomopsis spray, coverage should be maintained from 10” shoots through pea-sized fruits. This period of the early season is the time to use the best fungicides, the highest rates, and follow all the recommended cultural management practices.

Table 1 Spray program coverage recommendations for early season grape disease management.

Disease	**Dormant**	**1-5”**	**6-10”**	**Pre-bloom**	**Bloom**	**Pea-sized**	**Berry Closing**	**Veraison**	**Post-Veraison**
Anthracnose	X	X	X	X	X	X			
Phomopsis		X	X	X	X	X			
Black Rot			X	X	X	X			
Powdery Mildew			X	X	X	X	X	X	X
Downy Mildew				X	X	X	X	X	X
Botrytis					X		X	X	X
Sour Rot									X

Sprayer Calibration

When is the last time you calibrated your sprayer? If you can't remember, it is likely time. Ideally, sprayers should be calibrated annually. Proper sprayer calibration will ensure that the product you're applying can do the job you've paid for it to do. Maximizing spray coverage through proper sprayer calibration will maximize the dose of fungicide the pathogen is exposed to at any given rate of application. Remember, fungal pathogens only respond to the dose of product applied to the part of the plant where infection is taking place, not the dose of product you placed in the spray tank. The FRAME Network released an informative article titled 'Avoiding Selection of Fungicide Resistance' that can be found at http://s3-us-west-2.amazonaws.com/sites.cahnrs.wsu.edu/wp-content/uploads/sites/66/2019/04/18064944/2019-VEEN-SpringFinalCorrected.pdf on the important role sprayer calibration and proper application play in preventing resistance development. Andrew Landers from Cornell additionally has a wide array of helpful vineyard spraying articles that can be found at http://web.entomology.cornell.edu/landers/pestapp/grape.htm.

Fungicide Resistance

Here are some general considerations about fungicide resistance stewardship to keep in mind as you design your seasonal spray program and three rules to live by:

1) A durable spray program will include both contact protectants and systemic fungicides for post-infection activity.
2) Always ROTATE at-risk fungicides with effective, unrelated materials from a different FRAC code.
3) Apply at-risk materials in combination with another unrelated fungicide that's active against the target disease, either through tank mixing or use of a pre-packaged product containing two or more effective ingredients.

Low risk is NOT the same as no risk! ALL fungicides for grape disease management have varying capacity to lose efficacy due to resistance development. The Fungicide Resistance Action Committee (FRAC or "group") assigns a rating code to each fungicide group to indicate a relative risk of resistance development. Now these ratings do NOT mean that resistance is *unlikely* to develop to a group rated low-to-medium risk if products are overused. Rather, it means that for any given disease, resistance is likely to develop *first and with less use* to a high-risk product than a low-risk product. Globally resistance has been documented to ALL grape approved fungicides except for the broad-spectrum protectants, including the Group 40 (Revus) fungicides.

- High Risk: Strobilurins/QoIs (Group 11); Ridomil products (Group 4); benzimidazoles (aka Topsin-M, Group 1).
- Medium-to-High Risk: SDHIs (Group 7) fungicides, Rovral (Group 2), Ametoctradin (the non-group 40 half of Zampro, Group 45); Ranman (Group 21).
- Medium Risk: DMI fungicides (Group 3); AP fungicides (Group 9, aka Vangard, Scala, half of Switch); Quintec (Group 13); Vivando (Group U08); Group 40 fungicides (Revus/Revus Top, the other half of Zampro)

- Low-to-Medium Risk: Elevate (Group 17); Fludioxonil (Group 12, the other half of Switch).
- Low Risk: Mancozeb, captan, ziram, sulfur, copper, oils, salts.

Specific Recommendations for Grape Disease Control

- **DMI (FRAC 3) and strobilurin (FRAC 11) products should NOT be relied upon alone for powdery OR downy control**
- Fungicide groups that should be applied no more than 2-3x per season and never twice in a row
    - DMI (FRAC 3) – high resistance risk
        - DMI resistance (FRAC 3) in both powdery and downy mildew is present at varying levels throughout NY. The one exception to this appears to be difenoconazole (the "top" in Quadris Top & Revus Top), which still provides good control on powdery mildew even when other DMIs appear to be "slipping." That said, it is **RISKY** to rely on difenoconazole alone to control powdery mildew. DMIs have no efficacy on downy mildew.
    - Strobilurin (FRAC 11) – high resistance risk
        - **Do not apply without an unrelated tank-mix or pre-mix partner! FRAC 11 resistance is becoming more and more prevalent industry-wide and can hit like a ton of bricks with no warning.**
    - SDHI (FRAC 7) – moderate to high resistance risk
        - Stewardship of these high efficacy products is critical!!
    - Zampro and Revus/Revus Top (FRAC 40) – moderate resistance risk
        - Resistance has been documented in New York and eastern industry in recent year- low risk is not the same as no risk!!
- Fungicide groups that should be applied no more than 2x per season and ideally not twice in a row
    - Prolivo and Vivando (FRAC 50)
    - Quintec
- Ridomil should NEVER be applied more than once per season!!

Evaluating your spray program

The following considerations for reviewing and evaluating a spray program were inspired by guidance issued by the USDI SCRI FRAME Networks Eastern Program Design Workshop, Spring 2022. For more information on FRAME and an excellent explanation of fungicide resistance, check out the video: [Fungicide Resistance – What is it and how does it occur?]()

1) **When the program starts.** Spray programs should always consider *vine phenology*, or stage of development, when determining when to start spraying for the season. They

should also consider what diseases are of greatest concern during that phenological stage. Certain diseases, such as powdery mildew, downy mildew, and Botrytis bunch rot, do not warrant management approaches pre-budbreak. Other diseases, such as the various trunk diseases, Phomopsis, and anthracnose, may benefit from pre-bud break sprays. But you might also consider additional cultural practices to manage these diseases, such as the use of double pruning, or ensuring infected debris is removed from the vineyard.

2) **When the program ends.** Each grapevine disease has a different window for when it impacts the vine the most. While a spray program for all diseases may span the entire growing season, what you need to spray for will likely change as the season progresses. There are often distinctions between managing for disease on the fruit and managing for diseases on the canopy – and if you do a good job of managing disease on the fruit that may result in very little disease being able to spread to the canopy. As the season progresses, ask yourself – Are these extra sprays needed for the disease I am targeting?
3) **Products that are pre-mixes.** Some chemical manufacturers sell fungicides that are pre-mixes of two or more FRAC groups. This is done to either expand the range of diseases the new combined product can target, or to help with fungicide resistance management against a single target disease. But this can also make FRAC group rotations difficult, if you are not paying close attention to both the FRAC code and active ingredient. For example, if one were to spray Inspire Super (FRAC 3 + 9), followed by Revus Top (FRAC 40 + 3), not only have you sprayed a FRAC 3 back-to-back, you sprayed the *same* FRAC 3 product (difenconazole).
4) **Product choices at different times of the year.** Not only do products have different FRAC groups, they also have different basic properties. Some work as contacts, which mean they can only impact the target disease if they come into direct contact with it. Contact products can be very effective, but they typically need very good coverage, which can be hampered by rain, wind, and very rapid vine growth. Some products are systemic, which means they can be absorbed by the plant and move locally within the plant to the target disease. This ability to be absorbed means they can withstand things like rain better than contact products. There needs to be sufficient grape tissue present for the product to be absorbed (i.e., sprays are not optimized if applied at very early season), and they can become diluted in the plant if applied right before a period of rapid vine growth. *PREHARVEST INTERVALS (PHI):* There are some products that have very long pre-harvest intervals (over 30 days). This means that if these products are sprayed, the fruit cannot be harvested until that preharvest interval is met. Thus, products with long preharvest intervals should be avoided after the fruit set period, just to ensure harvest is not delayed due to a product application.
5) **Product intervals in response to disease pressure.** When disease pressure is high, which occurs when the plant has susceptible tissue and the weather is favorable for the pathogen, the shorter intervals listed on the label should be used. When disease pressure is low, such as the case when grapevine tissue ages (for some diseases), or when weather conditions are not favorable, the longer intervals on the label may be appropriate.
6) **Inherent resistance in the grapevine.** As mentioned above, the grapevine is not susceptible to all diseases, all season long. Sometimes, tissue is simply protected

from infection due to slow growth or physical barriers such as a lot of leaf hair. Sometimes the tissue itself develops an actual resistance response to infection. Know when / if the grapevine is susceptible to the diseases you are targeting, and only spray for during periods of susceptibility.

Biopesticides

Below is a consolidated version of my Grapes101 article for Appellation Cornell published entitled "Digging into the Data: Biopesticides for Grape Disease Control." For the full article, please visit https://grapesandwine.cals.cornell.edu/newsletters/appellation-cornell/2022-newsletters-0/issue-48-march-2022/grapes-101-biopesticides/. For more detailed efficacy information, please visit the 2022 Organic Production and IPM Guide for grapes (https://ecommons.cornell.edu/handle/1813/42888.3).

"Biopesticides" have been moving into the mainstream and generating quite a bit of interest. While earlier versions gained a reputation for only modest efficacy in comparison with conventional synthetic fungicides, new products are proliferating – and offer comparable performance that sometimes rivals the 'gold standards' that growers rely upon. Biopesticides have fundamentally different modes of action from traditional chemistries. Understanding this difference is key to understanding how biopesticides can fit into an integrated grape disease management program.

Biopesticides are products derived from such natural materials as animals, plants, bacteria, and certain minerals. For example, kitchen products such as canola oil and baking soda have antimicrobial applications and are considered biopesticides. Because it is often difficult to determine whether a substance meets the criteria for classification as a biopesticides, the Environmental Protection Agency (EPA) has a special committee dedicated to making these decisions. Biopesticides are the fastest growing market sector of pesticides despite only representing 5% of the global pesticide market. As of August 31, 2020 the EPA has 390 biopesticide active ingredients registered. In the 5-year period between 2015 to 2020, almost 100 new biopesticide active ingredients were registered with the EPA. Since biopesticides tend to pose fewer risks than conventional pesticides, EPA generally requires much less data to register a biopesticide than to register a conventional pesticide. In fact, new biopesticides are often registered in less than a year, compared with an average of more than three years for conventional pesticides.

Just like how we separate traditional chemistries by their modes of actions, there are different types of biopesticides. The EPA defines three types of biopesticides, however these can be broken down further.

Biochemical pesticides. A biochemical pesticide is a naturally occurring substance that controls pests and/or pathogens by non-toxic mechanisms. Biochemical pesticides can have plant, animal, microbial, or mineral origins. In terms of grape disease control, the most common biochemical pesticides are plant extracts and microbial extracts.

1. *Plant Extracts*. Before people came along, plants had to save themselves from pathogen and pest threats. You're likely more familiar with these sorts of

compounds than you realize, as many naturally occurring compounds, such as caffeine and nicotine, have been harnessed for eons for non-agricultural, human use. An example of a plant extract biopesticide is Regalia.

2. *Microbial extracts*. Microbes have been fighting each other for far longer than they've been fighting plants. Microbial extracts, such as penicillin, the first antibiotic, are the foundation of much of modern human medicine. An example of a microbial extract biopesticide is Oso.
3. *Mineral & misc. compounds.* Oils and mineral compounds are considered biochemical pesticides under the EPA's definition. This category includes a variety of commonly used pesticides including oil (JMS Stylet Oil), silicon (Sil-Matrix), copper (Cueva), phosophorus acid (Phostrol), and hydrogen peroxide (Oxidate).

Microbial pesticides. A microbial pesticide consists of a living microorganism (e.g., a bacterium, fungus, virus, or protozoan) as the active ingredient. Microbial pesticides can control many kinds of pests and pathogens, although each separate active ingredient is relatively specific for its target. For example, there are fungi that control certain weeds and other fungi that kill specific insects.

The subcategory of *biofungicides* describes formulations of living organisms used to specifically control the activity of plant pathogenic fungi. The idea behind biofungicides is based upon decades of scientific study demonstrating that some beneficial microorganisms, usually isolated from soil, can hinder the activity of plant pathogens. There are four main modes of action:

1) *Competition.* The idea behind this mechanism is that a plant pathogen can't take hold if there isn't any room for it grab on! These biofungicides compete with plant pathogens for nutrients, infection sites, and general space (a "niche") without harming the plant. For example, they may colonize the entire root surface, leaving no room for a root pathogen to attack. Additionally, some biofungicide organisms can metabolize plant exudates that would normally attract plant pathogens or stimulate their growth. An example of this type of biofungicide labeled for grape disease control is Double Nickel.
2) *Parasitism and antibiosis.* These biofungicides take a more direct approach to plant disease control by harnessing microbe-microbe warfare. They directly attack, consume, or produce compounds that destroy plant pathogens. An example of this type of biofungicide labeled for grape disease control is Howler.
3) *Defense induction.* These biofungicides don't act upon other microbes, but instead activate the plant's own defense system so that it can better protect itself against plant pathogens. By turning on Systemic Acquired Resistance (SAR), these biofungicides improve the plant's response to pathogen attack by priming the production of plant defense compounds at the site of active invasion as well as throughout the plant (systemically). An example of this type of biofungicide labeled for grape disease control is Lifegard.
4) *Plant growth promotion.* The biofungicides also act upon the plant, however they do not engage the plant's defense system. They instead promote plant health and growth,

thereby improving the plant's ability to turn on its own defenses and fight off plant pathogens.

The third category of biopesticide, *plant-incorporated protectants (PIPs)* are uncommon in grape disease control. These are pesticidal substances that plants produce from genetic material that has been added to the plant. For example, scientists have produced maize varieties that are resistant to the European corn borer by incorporating the gene for the Bt pesticidal protein into the plant's own genetic material. Then the plant, instead of the Bt bacterium, manufactures the substance that destroys the pest. The protein and its genetic material, but not the plant itself, are regulated by EPA.

As stated previously in the powdery mildew and downy mildew sections, when considering using biopesticides, it is important to remember that they act like a lock on a door. A good lock will stop opportunistic, weak thieves, but determined, strong thieves, or thieves in sufficient numbers, can still break through with enough force. And most importantly, biopesticides can't stop a thief that is already inside the house when the door is locked. For most effective use, a biopesticide must be in place ***before*** pathogen infection begins as their action is majorly protective. The key exception to this is Stylet Oil, which is a highly effective powdery mildew eradicant. Biopesticides must be reapplied frequently both to protect new growth and to ensure that effective populations of the microorganisms are present in the case of live microbe biofungicides. Additionally, because some biofungicides consist of living organisms, they often have different storage, shelf life, and handling requirements than conventional fungicides.

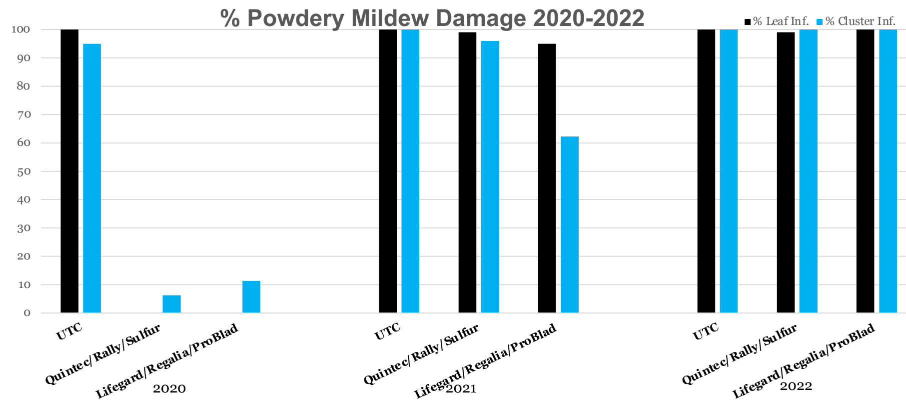
So—why use biopesticides? Biopesticides are usually inherently less toxic than conventional pesticides, as they generally affect only the target pathogens and closely related organisms. This is in contrast to broad spectrum, conventional pesticides that may affect organisms as different as birds, insects, and mammals. Biopesticides often are effective in small quantities and often decompose quickly, resulting in lower exposures and largely avoiding environmental runoff issues. Additionally, most biofungicides have short reentry intervals (0-4 hours) and no pre-harvest interval restrictions, making it easier to coordinate vineyard logistics around their application. Biopesticides do not carry the same risk of pathogen resistance development that more targeted conventional chemistries have given their diverse mechanisms of action. For example, it is impossible for pathogens to develop resistance to Lifegard, because Lifegard is a defense inducing biofungicide and does not directly act upon the pathogen.

Over the years, Cornell Grape Pathology, under both its current and former captains Gold and Wilcox, has evaluated a number of different types of biopesticides in our seasonal spray trials. While there's many ways we could delve into the data, we sought to summarize our findings simply to provide general insights into how biopesticides perform for grape downy and powdery mildew control. The graphs and table that follow present average percent incidence control across all years studied. Percent (%) control compares treatment performance to the total amount of disease in the untreated control each year. For both powdery and downy mildew, we evaluated percent control on leaves and on grape clusters separately.

Overall, we find that biopesticides performance is pressure dependent. In low pressure years, biopesticide + conventional rotations provide comparable control to conventional only rotations. However, in high pressure years, they struggle to perform (*but so do the conventional!*).

Biopesticide performance is pressure dependent

In **low pressure years**, biopesticide rotations provide comparable control to conventional rotations



- **2020 – low pressure** – comparison combo programs worked well
- **2021/22 – high pressure** –all materials failed

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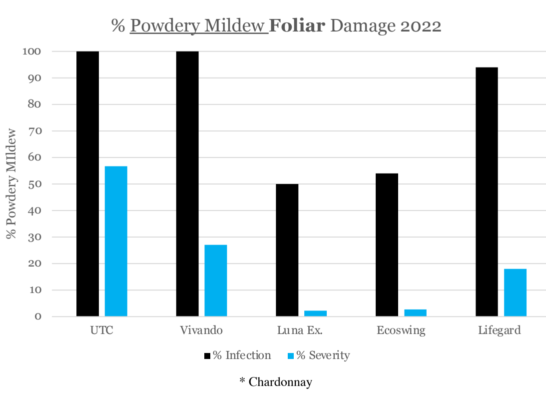
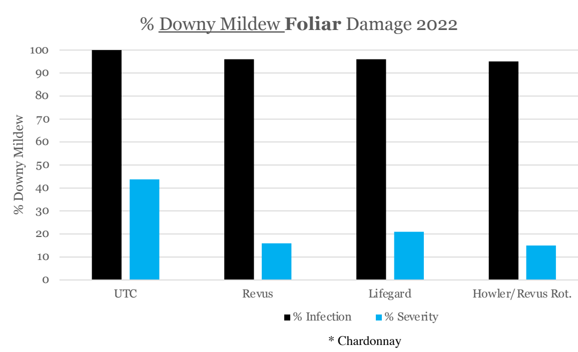
Biopesticide performance is pressure dependent

In **high pressure years**, we see control failures across the board (especially for DM)





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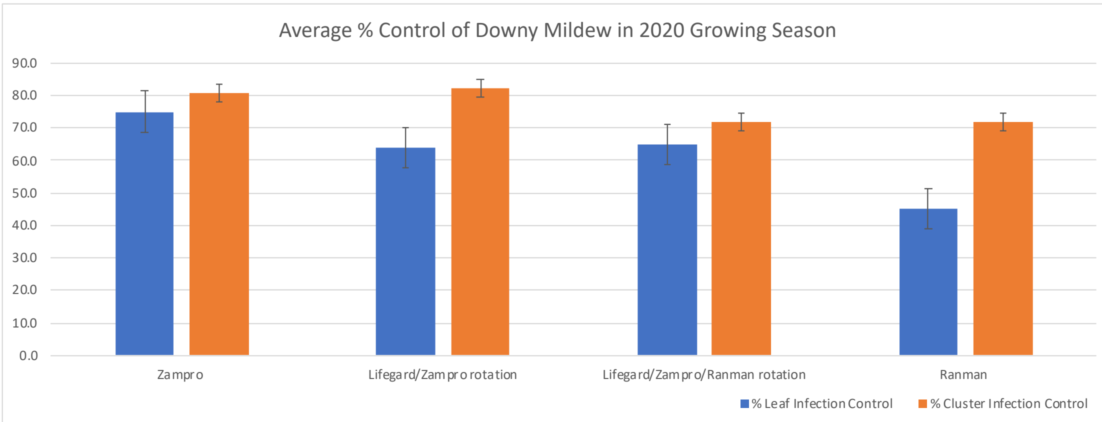
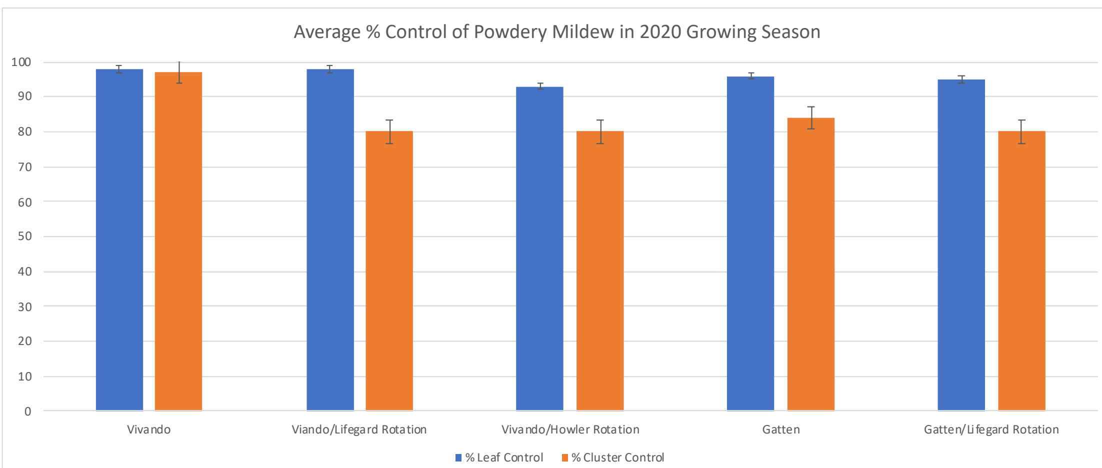
Thus, we find that biopesticides can complement traditional chemistries. When used as a component of integrated grape disease management, biopesticides can reduce the use of conventional pesticides while retaining crop quality and yield. For example, in the 2020 season, a moderate pressure year for both powdery and downy mildew, we saw that a rotation of Lifegard and Zampo provided nearly equivalent downy mildew control to a straight program of Zampro alone. For powdery mildew control in the 2020 season, we saw those rotations of Vivando/Lifegard and Vivando/Howler provided nearly equivalent control to Vivando straight through. We saw the same repeated when a rotation of Lifegard/Gatten was compared directly to Gatten. **In both these cases, we found that using a biopesticide in rotation reduced overall conventional chemistry usage by half while maintaining highly effective disease control!**





Integrating biopesticides into a disease control program reduces the control pressure placed on conventional chemistries, slowing the development of fungicide resistance in target pathogen populations. Protecting the longevity of highly effective, conventional chemistries is essential for the long-term health and sustainability of the New York grape industry. **Using biopesticides in your early or late season disease control program will help ensure that the traditional chemistries we rely on for robust powdery mildew and downy mildew control during the critical period of pre- to post-bloom will be in our toolbox for years to come.**

Seasonal Program Design: Considerations by Growth Stage

Dormancy

An early season dormant spray should only be considered to 1) clean up a serious anthracnose problem or 2) if you are pursuing organic/biointensive production. A dormant spray will not replace the need for in season sprays and will likely not be economical if you well-controlled fungal diseases in the prior season. Dormant sprays are most effective for anthracnose control, but will have activity on Phomopsis, powdery mildew, and black rot as well. Dormant sprays have no impact on downy mildew. If you meet the conditions for a dormant spray, use liquid lime sulfur at an approximate rate of 5-10gal/A but check the label to ensure proper protocol. Although lime sulfur may be considered an organic treatment, it is a highly caustic and corrosive material that can cause irreversible eye damage and skin burns. As with all pesticide products, users should follow precautionary statements and use personal protective equipment (PPE) described on product labels.

One to Five-Inch Shoot Growth

This is the most critical time of season to control Phomopsis, especially in blocks with a history of this disease, *especially* for Concord and Niagara growers. Although several products containing Group 3, Group 7, and Group 11 fungicides are labeled for control of Phomopsis, these are all weaker than the protectants (mancozeb, captan, and ziram) and should not be relied upon at this growth stage for Phomopsis control. Though rare, Anthracnose control may be needed at this stage as well, but a protectant spray for Phomopsis should take care of this. If temperatures remain above 50˚F for long stretches of the day during this growth stage, you may want to consider including a product for powdery mildew control on highly susceptible *vinifera* cultivars, especially in blocks that had significant foliar powdery mildew late in the prior season.

Six to Ten-Inch Shoot Growth

Vinifera cultivars and high-susceptibility hybrids need powdery mildew and downy mildew control beginning at this stage. This is one of the best times to use JMS and other oils, or other eradicant material against young powdery mildew infections that are just getting started. Now is the time to start thinking about downy mildew control. If you have a susceptible variety, rainfall has been greater than 0.1in, and temperatures above 52˚F have occurred recently or are anticipated, then include a downy mildew product in this spray. This especially important if downy mildew was prevalent in the prior season. Phomopsis infections on rachis and fruit can still be a concern at this stage in wet years, particularly in blocks with history of the disease. Anthracnose should be controlled at this stage by growers for whom this is a concern. Black rot control can likely wait until the next growth stage unless it was a significant problem last season (high primary inoculum levels) and weather is wet (conducive environment).

Immediate Pre-Bloom to Early Bloom

THIS IS THE MOST CRITICAL TIME OF YEAR TO CONTROL **POWDERY MILDEW, DOWNY MILDEW, AND BLACK ROT**. USE YOUR BEST MATERIALS AND DON'T CUT ANY CORNERS ON RATES, SPRAY COVERAGE, OR INTERVALS!! THIS SPRAY SHOULD INCLUDE BOTH A CONTACT PROTECTANT AND SYSTEMIC/CURATIVE. This spray is also important for Phomopsis and anthracnose, but it is likely that the products chosen for downy, powdery, and black rot will cover them. If you miss this spray, you're going to have a rough year.

Bloom

This bloom spray is critically important for Botrytis management on susceptible varieties. Vangard (or Inspire Super), Switch, Scala, Elevate, Pristine, Rovral/Meteor/iprodione generic, and Luna Experience applied around the bloom period often provide beneficial control of Botrytis on susceptible varieties, particularly in wet years. If sulfur was the only powdery mildew material in your immediate pre-bloom spray, it is best to reapply about now on highly susceptible *viniferas* rather than wait until post-bloom. If this is the case, keep your spray interval short, *especially* if it has rained since your last application or is expected soon. Something to consider with this spray is whether or not to tank mix. If you tank mix your botrytis-specific materials with something targeted at one of the other diseases, then you'll be distributing it throughout the canopy when it is only doing something useful on the clusters. If possible, it is best to apply your Botrytis-specific materials directly to the clusters rather than a tank mix.

One to Two Weeks Post-Bloom

10-14 DAYS AFTER YOUR PRE-BLOOM SPRAY IS A CRITICAL TIME OF YEAR TO CONTROL POWDERY MILDEW, DOWNY MILDEW, AND BLACK ROT. USE YOUR BEST MATERIALS AND DON'T CUT ANY CORNERS ON RATES, SPRAY COVERAGE, OR INTERVALS!! THIS SPRAY SHOULD INCLUDE BOTH A CONTACT PROTECTANT AND SYSTEMIC/CURATIVE. If weather has been warm and cloudy, increase either the rate or quality of your powdery mildew material for highly susceptible varieties. If you haven't controlled for Botrytis yet, this spray should include a material for that (especially if weather has been favorable). If you miss this spray, you're going to have a rough year.

Three-Four Weeks Post-Bloom (Pea-Sized Fruits)

The second post bloom spray period is still an important stage for early season disease control, but the most critical time of year for fruit infection prevention has passed. *Vinifera* varieties will still require black rot control, especially if weather has been wet, especially if infections are visible on the vine. Natives and resistant hybrids can now likely move forward without black rot specific products *unless* there is a strong history of disease in the block. At this stage, fruit will now be mostly resistant to powdery mildew, but new foliage will remain highly susceptible. If you have a highly susceptible *vinifera* variety, it may behoove you to continue to control PM on clusters to help reduce risk of later season opportunistic bunch rots or wine-spoiling microorganisms.

It is important to maintain coverage of new *vinifera* foliage as shoot growth continues here on out to reduce primary inoculum for next season. Avoid applications of fungicides at risk of resistance development, *especially* if there's enough powdery mildew present in the vineyard that it's easy to spot without even trying. At this time, Concords can now tolerate a reasonable bit of powdery mildew unless the crop is large or ripening conditions are marginal, so if you prefer a minimal program, you can likely stop spraying now. That said, if conditions are marginal, one more powdery mildew spray is often warranted.

Foliar downy mildew will continue to remain a threat from here through end of season and can quickly turn into an epidemic on unprotected susceptible cultivars if we have regular periods of conducive weather. Clusters are still susceptible to downy mildew and will continue to need protection for a couple more weeks, *especially* if the disease is already established in the vineyard. Defoliation in the late season by downy mildew puts you at risk of delayed ripening and impact accumulation of vine reserves for early shoot growth next season. Anthracnose may still be a concern on berries of susceptible varieties.

Summer Sprays

Once we reach berry closure/touch, the most critical control period for powdery mildew, black rot, and downy mildew is well over, but foliage will still need protection to prevent late season defoliation from powdery and downy. Bunch closure is an important time for Botrytis control on susceptible cultivars especially if conditions are wet. Clusters will likely need Botrytis protection veraison and post-veraison as well. Sour rot will require specialized control starting around 12-13 Brix. The current best practice recommendation is to use a combination of insecticide and anti-microbial (Oxidate 2.0) weekly through harvest once you start seeing the flies but before you smell the rot, starting around approximately 12-13 Brix but depends on the weather conditions that season. If you wait until you smell the rot to start spraying, your weekly sprays will only keep disease at the level at which it first appeared. Spraying weekly will NOT get you more control than 1-2 combo sprays *if and only if* you wait to start spraying until you see symptoms.

Sources & Acknowledgments

The information presented in this article is primarily sourced from the body of work of my predecessor, Professor Emeritus Wayne Wilcox, the 2022 New York and Pennsylvania Pest Management Guidelines for Grapes, FRAME Networks resources, and the American Phytopathological Society Compendium of Grape Diseases, Disorders, and Pests (2nd edition), and my own experience. Great appreciation is extended to Kathleen Kanaley, Dave Combs, Wayne Wilcox, Tim Martinson, and Hans Walter-Peterson for their advice, contributions, and helpful feedback.

Disclaimer: Please read the pesticide label prior to use. The information contained in this article is not a substitute for a pesticide label. Trade names used herein are for convenience only. No endorsement is intended for products mentioned, nor is lack of endorsement meant for products not mentioned. Application of a pesticide to a crop or site that is not on the label is a violation of pesticide law and may subject the applicator to civil penalties up to $7,500. In addition, such an application may also result in illegal residues that could subject the crop to seizure or embargo action by appropriate state authorities and/or the U.S. Food and Drug Administration. It is your responsibility to check the label before using the product to ensure lawful use and obtain all necessary permits in advance of application.