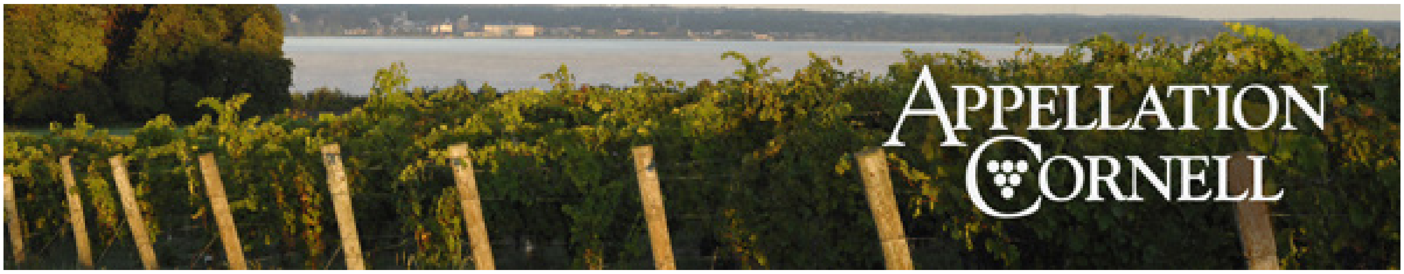

Research Focus

Grape Disease Control: Taking Stock and Looking Forward

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Photo by Tim Martinson

Wayne Wilcox

Controlling the plethora of fungal diseases common to our climate has always been an important part of growing grapes in New York and other Eastern regions. This has only become more important since I assumed the lead of Cornell's grape pathology program in 1994. Major segments of the industry have shifted their focus to *V. vinifera* and interspecific hybrid varieties that typically are more disease susceptible (sometimes, much more) than the native cultivars long traditional to the area. At the same time, those who do grow the natives have been squeezed financially to maximize tonnage while limiting both disease losses and the inputs to control them. All while the market's demand for quality keeps rising.

Because of these trends, Eastern growers and their advisors have become increasingly sophisticated in their management of the fungal disease complex that they must contend with every year. It has always been my goal to help provide them with the knowledge to support this, by focusing on the three pillars of what I consider to be IPM, that is, Intelligent Pest Management:

- **Understand the biology of a specific disease.** What are the environmental factors that make it click? How does it get started in the first place each year? When during the season is the pathogen that causes it most active? Knowing the above, what non-chemical viticultural practices can we employ to reduce disease development?
- **Understand the vine's susceptibility to specific diseases.** What are the differences among grape species and cultivars? What are the seasonal changes in susceptibility—particularly, *when* during the crop's development is it critical to focus your spray program and when can you afford to save some time/money and ease up?
- **Understand the characteristics of the individual fungicide tools available.** How well does each work against specific diseases? What is its so-called physical mode of action—does it provide protective, post-infection, and/or antisporulant activity? What is the risk of resistance development, and how can we help manage that?

As I prepare to retire from Cornell, I'd like to take this opportunity look back on a few aspects of the work that's been done by those in my program and with whom I've cooperated to answer some of these questions as they pertain to the major fungal diseases of grapes in New York and other regions.

Powdery Mildew (PM). Powdery mildew is a unique disease in the sense that the causal fungus colonizes infected leaves and berries almost entirely on their **surface**, whereas all of our other fungal pathogens grow within the infected organs.

Thus, the PM fungus is uniquely affected by environmental variables such as relative humidity (RH), since the fungus draws its water from the vapors in the air; ultraviolet (UV) radiation; and various topical chemicals (e.g., oils, salts such as bicarbonates) that growers might apply—all of which are largely irrelevant to other pathogens that are living within the leaves and berries.

Relative humidity. In an extensive series of lab experiments, postdoctoral associate Julie Carroll showed that RH has a major effect on PM development. As shown in **Figure 1**, the percentage of inoculated Riesling leaves covered with mildew more than doubled when they were subsequently held at 80% RH than when they were held at 40% RH.

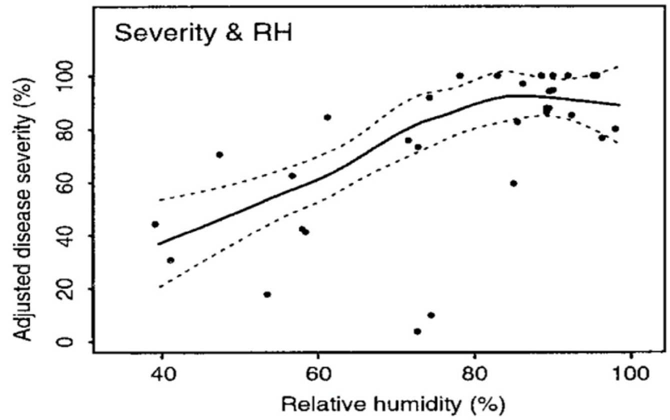

Figure 1. *The effect of relative humidity on PM severity (% leaf area diseased) on cv. Riesling seedlings incubated at various constant RH levels after exposure to spores of the PM fungus. The center black line represents the statistically-estimated mean, the dotted lines represent the calculated 95% confidence interval (statistical range).*

Effect of sun exposure. Although it has long been "common knowledge" that PM is more severe in shaded regions of the vineyard (along wood edges, within dense canopies, etc.), graduate student Craig Austin showed just how dramatic this effect is *(See Heat and UV Radiation from Sunlight Exposure Inhibit Powdery Mildew in Appellation Cornell Issue #2)*. For example, he inoculated leaves of Chardonnay vines that were located either (i) immediately either next to or (ii) about 200 feet away from a tall group of trees, on either (a) the sun-exposed outer edge of the canopy, or (b) within the inner portion of their dense canopy, thereby providing four different treatments with varying levels of natural shade (**Fig. 2**).

The resulting disease severity increased substantially with each increasing level of shade, becoming **8 to 40 times more severe** on the most heavily shaded leaves (interior canopy of vines next to the trees) compared to the no-shade leaves on the exterior of vines away from the trees, depending on the year.

Compared to leaves in full sun, those in the shade had both (i) lower temperatures (an average of 12°F lower than leaves in the sun), and (ii) just a fraction of the exposure to UV radiation. The PM fungus stops growing and can even die at temperatures >90°F (common on the leaves on a sunny summer day, when they are 12° hotter than the ambient air). And in both field and lab studies, Craig showed the even more dramatically harmful effect of UV radiation on this non-pigmented fungus PLUS the fact that UV combines with high temperatures to suppress disease development in a synergistic manner (2 + 2 = 5).

Given the above, we would expect that canopy management practices that promote balanced levels of sun exposure on the clusters would help to reduce

Photo by Craig Austin

Figure 2. *Vigorous Chardonnay vineyard where PM development was examined under four different shading levels: Inner and outer canopies away from and within the shadows provided until early afternoon each day by adjacent trees.*

PM on them. This was shown to be true when we compared an Umbrella-Kniffen training system versus a VSP system (which provided fewer shoots per foot of row) and employed leaf pulling treatments around the clusters that began either at fruit set or 5 weeks later. Using the VSP system and removing the cluster-surrounding leaves at fruit set (but not 5 weeks later, when berries were no longer susceptible to infection) reduced PM on the clusters by nearly 40% relative to UK-trained vines with no leaf removal.

Canopy management and spray deposition. Of course, canopy management practices that promote light penetration also promote spray penetration.

Using the different canopy densities in the Umbrella-Kniffen/VSP vineyard, Craig showed that for each leaf layer between the sprayer and the cluster, spray deposition on that cluster was reduced by one-half (!).

In subsequent cooperative work with Dr. Andrew Landers, we expanded this portion of the study to include commercial Finger Lakes vineyards of different cultivars and training systems. This greatly expanded data set showed the same thing: For each increase of 1.0 in the Cluster Exposure Layer (CEL) value (basically, the average number of leaves between the cluster and the sprayer), deposition was reduced by 50% **(Fig. 3)**

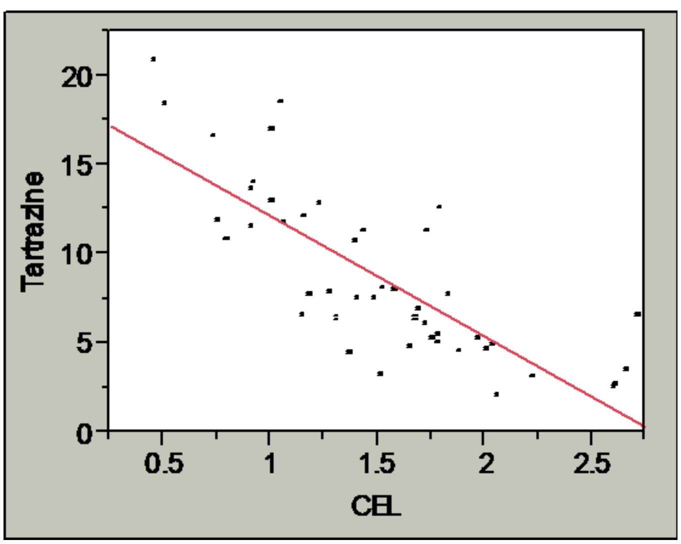

Figure. 3. *Effect of canopy density (cluster exposure layer = CEL) on deposition of a spray tracer dye (tartrazine) onto grape clusters in five Finger Lakes vineyards. Vines were treated in early July with a conventional airblast sprayer applying 50 gallons/acre.*

PM fungicides. With the "help" (i.e., they did all of the work) of long-time technician Duane Riegel and, more recently, Dave Combs, we have conducted a series of fungicides trials every year on hybrid and *vinifera* (Chardonnay) grapes in Geneva. Ditto for many years on Concords in Fredonia with the help of Rick Dunst and Mike Vercant. This has provided invaluable help in determining the basic efficacy of new materials against various diseases as they become available and comparing them to other current options. These detailed fungicide trials have also allowed us to examine specific fungicide activities in more depth.

For example, in a series of field and lab experiments (the latter conducted primarily by technician Judy Burr) examining the activities of sulfur, we found that:

- Contrary to previous "conventional wisdom" that it is strictly a protective fungicide, sulfur provides significant post-infection and even eradicative activity if applied from the time that a spore lands on the vine until a readily-visible colony has developed (about a week under typical summer conditions).
- Contrary to previous "conventional wisdom" that it is relatively ineffective at temperatures below 65°F, sprayable sulfur formulations are comparably active at all temperatures where the PM fungus is active.
- In rainy seasons especially, sulfur activity is increased by any of the following: utilizing a "micronized" rather than wettable powder formulation; increasing the rate; and/or adding a spreader-sticker adjuvant.

Sulfur residue persistence in the field. In another study conducted in cooperation with Dr. Gavin Sacks in the Department of Food Science, graduate student Misha Kwasniewski examined the potential role between late-season sulfur (S) applications and wine defects resulting from excessive residues at harvest. A major question for both producers and wineries, this issue had seldom been addressed experimentally due to the lack of technology for measuring S residues in a way that would allow it. Misha and Gavin first developed a technique to make such measurements, then we undertook a series of field experiments.

We found, unsurprisingly, that residues decreased as we reduced the rate of S applied and if we used a wettable powder rather than micronized formulation (the tenacity of the micronized formulations, which improves disease control, also causes higher residues with late-season use). For red-wine production, S residues generally regarded as "safe" required that applications be stopped 5 weeks before harvest.

However, Misha showed that for typical white wine production, where the must is clarified prior to fermentation, virtually all of the sulfur residues settle into the lees at the bottom of the tank within 24 hr after crushing, regardless of how high they were to begin with. In other words, late-season sulfur use should be a non-issue for standard white wine production.

Fungicide resistance. By the mid-1990s, the available sterol-inhibitor (more specifically, the DMI or FRAC Group 3) fungicides were beginning to lose potency due to resistance development. Over a number of years since, efforts by graduate students Eugene Erickson, Frank Wong, and technicians Judy Burr and Duane Riegel shed a lot of light onto how such resistance develops and how to manage it.

Monitoring sensitivities of the PM fungus population in a "resistant" vineyard and comparing that to the population in a "baseline" vineyard (never exposed to these materials) showed that the population "shifted" over time in the resistant vineyard to become predominated by individual PM colonies that required higher and higher doses of these fungicides to get a certain level of control.

For example, in 1995, the most common cohort of individuals in the resistant vineyard needed 8 times as much myclobutanil (active ingredient in Rally) for control as those in the baseline population (0.25 vs. 0.03 µg/ml), and 4 years later they required 20 times as much (1.02 vs. 0.03 µg/ml) **(Fig. 4)**.

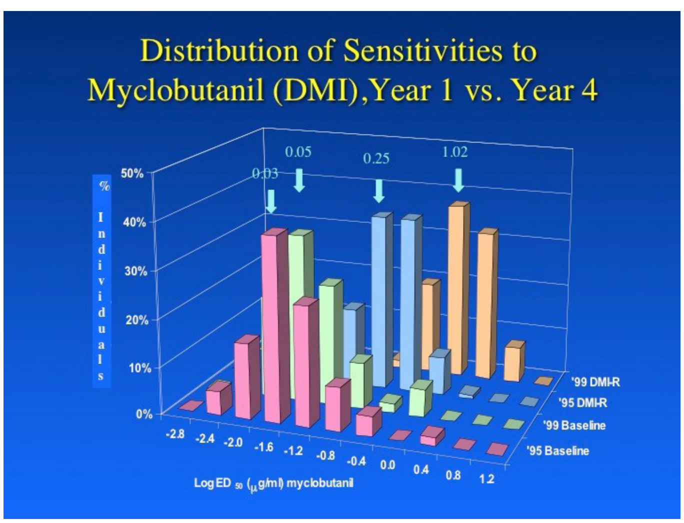

Figure 4. *Shifting distributions of sensitiviy to the DMI fungicide myclobutanil (Rally) among populations of the PM fungus in a DMI-resistant versus baseline vineyard over a 4-year period. Log ED50 values refer to the dose (rate) of fungicide required to control an individual PM colony.*

The practical effect of such rate-dependent shifts was illustrated when we sprayed Rally at either 2 or 4 oz/A in the resistant vineyard in 2000. We obtained approximately 80% control with the higher rate and only 30% control with the lower rate.

When we assayed populations of the PM colonies that developed in the two treatment groups and compared them to the unsprayed vines, we found that both rates provided almost complete control of DMI-sensitive individuals (the types making up the vast majority of the baseline population) but that the lower rate provided far less control of the "partially resistant" ones that required a higher dose for control.

This meant that not only was control compromised by the lower dose, but that it kept "shifting" the population by preferentially allowing these less-sensitive individuals to survive. Thus, full dosage (rate in the tank + coverage) proved to be critical.

As time went on, even full rates of the older DMIs became inadequate in some vineyards. However, we found that some of the newer DMIs that have become available over the past decade, particularly difenoconazole (Revus Top, Quadris Top, Inspire Super) were far more active than the previous materials on an ounce-for-ounce basis of active ingredient. This means that applying difenoconazole at its label rate is like applying the older materials at several multiples of their allowable rates.

In our field trials, this more-active compound provided good control even when some of the older products did not. Recent trials indicate that the same may be true for the active ingredient flutriafol (Rhyme, Topguard EQ). Unlike the DMI fungicides, resistance to the QoI or strobilurin fungicides is NOT rate dependent, and mixes with an effective partner (e.g., the boscalid component of Pristine) is the only way of controlling individuals resistant to these materials once they are present.

Period of berry susceptibility. Work by my colleague David Gadoury established that grape berries are extremely susceptible to PM from the time that flowers are ready to open (the fungus can establish itself in the flower stem and then move onto the berry as it forms) through the time that berries are BB-sized or a bit larger; then, they begin to develop age-related resistance and few new infections develop once they are about 4 weeks old.

Over the years, we have run numerous fungicide trials in which we vary our spray programs during this immediate pre-bloom through early post-bloom period. Not surprisingly, we have consistently found that we get our best control of cluster infections when we focus use of our best fungicides and/or employ conservative spray intervals during that period of maximum berry susceptibility.

Michelle Moyer, a former graduate student with David Gadoury and Bob Seem, made a nice start on identifying the environmental conditions during this period that would trigger a red flag to amp up the spray program (or, conversely, the conditions that would indicate a less-severe situation where "average" vigilance is sufficient).

Seems that it could be beneficial in the future to develop a specific set of guidelines to give to growers and advisors based on this information (e.g., a disease risk index), then put it to the test in various situations to see how well it works.

***Botrytis* Bunch Rot (BBR).** In addition to multiple spray trials examining product efficacy, fungicide physical modes of action, and spray timing effects, much of our work on BBR has focused on various factors that initiate BBR and cause it to spread.

Much of this work, spearheaded by graduate student and subsequent post-doc Stella Zitter, was detailed in a 2016 edition of this newsletter *(See Botrytis Bunch Rot: A Disease Requiring Integrated Control in Appellation Cornell, Issue #27).* Some of these take-home messages were:

- Although infections can occur during the flowering period and remain latent (dormant) until the preharvest period, relatively few of them become active then and cause rot.
- Nevertheless, those bloom-initiated infections that do become active post-veraison can be critically important initial sources of disease for rapid spread during the last few weeks before harvest.
- Preharvest spread is MUCH greater through tight clusters as a result of berry-to-berry spread at the point of their physical contact.
- Such spread is even greater in berries with high nitrogen or high water content.
- Relatively little berry-to-berry spread occurs in loose clusters where berries have limited contact with each other.
- Factors that promote the activation of latent infections (i.e., cause them to rot berries rather than remain dormant) appear to be a result of the vine's response to various environmental factors, including high relative humidity in the atmosphere, high water content in the soil, and high nitrogen availability.
- The most important crop development stage or states for potentially applying BBR fungicides (i.e., late bloom, bunch closure, veraison, preharvest) varies among years, probably as a result of varying climatic conditions at these stages in the individual growing seasons.

As per the last point, better defining the conditions under which fungicides are recommended at these various stages (beyond "wet is more dangerous than dry") would be a major service to those who must manage the disease.

Black Rot. In a 5-year series of fungicide trials, we found that we always got near-perfect control of black rot when we applied effective fungicides at the start of bloom plus 2 and 4 weeks later, but omitting one of these three sprays often resulted in decreased control. Graduate student Lisa Hoffman looked into the details behind these results, and showed that it is because such sprays protect the berries throughout their period of susceptibility **(Fig. 5)**.

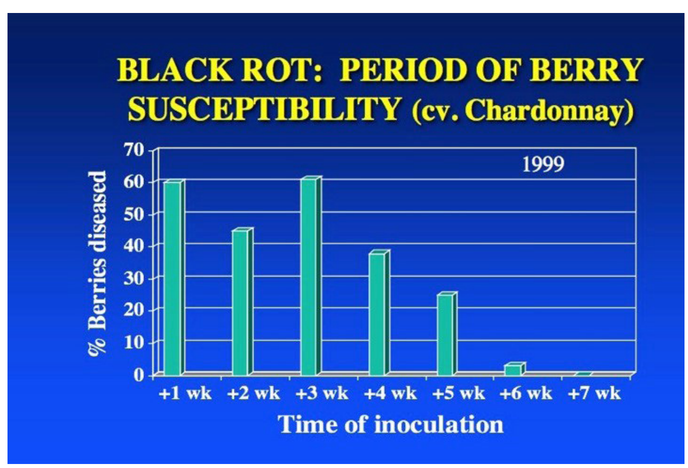

Figure 5. *Period of susceptibility of Chardonnay berries to black rot (BR). Berries on vines in the field were inoculated with spores of the BR fungus at weekly intervals following cap fall, as indicated.*

Among her other findings, Lisa demonstrated the major impact of a simple sanitation program, removing mummified berries from the vine during dormant pruning operations.

As shown in **Figure 6**, mummies on the ground finish producing their overwintering spores shortly after the start of bloom, whereas those retained in the trellis produce spores throughout the period of berry susceptibility into the summer. Furthermore, mummies in the trellis produce many more total spores (probably because they don't decompose as rapidly) AND they produce these spores immediately next to the new season's crop, making it more likely that the spores will find this "target".

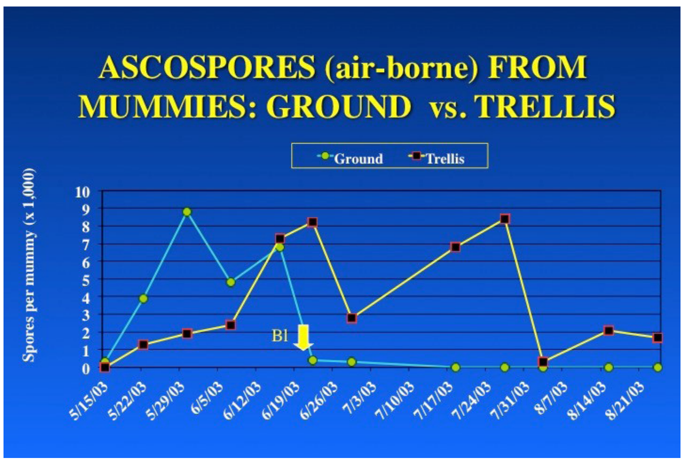

Figure 6. *Production of spores (ascospores) of the black rot fungus from overwintered mummies in the vineyard. At the time of dormant pruning, mummies were either dropped to the ground or retained in the trellis, then the production of spores was assayed from different samples at weekly intervals during the growing season. The yellow arrow denotes the time of bloom.*

Lisa also showed that DMI fungicides (she used Rally as an example) provide 7 to 10 days of post-infection activity against leaf infections, far more than indicated on the label. In subsequent experiments, we showed that these fungicides also provided nearly 90% control of berry infections when applied even 7 days after an infection period in the field, although their residual protective ability is limited. In contrast, the strobilurin fungicides (we used Abound as an example) provide much more protective activity but very limited post-infection activity.

Downy Mildew. Most of our downy mildew projects have focused on determining the efficacy and physical modes of action of various fungicide groups. One of our major projects was determining the physical mode of action of the phosphorous acid (a.k.a. phosphites, phosphonates) when they became available as generics in the early years of the millennium. A few of the major findings:

- These materials provide significant but limited protective activity (at least 3 days, sometimes up to 8), depending on the rate used, as well as the particular trial (weather, cultivar) and which leaves were being evaluated. Protective activity in the older leaves sometimes declined significantly after 3 days, particularly at lower label rates, as phosphonates are "shipped out" of them to the younger leaves and roots.
- They provide excellent "kick-back" activity against new infections. When applied 3 or 4 days after the start of an infection period, few lesions developed at either the low or high labeled rate and spore production from these few lesions was greatly to totally inhibited. When applied 6 days after inoculation, the small lesions that were just starting to become visible at that time continued to expand, but production of spores from the expanded lesions was greatly inhibited. Post-infection control was better when higher label rates were used and when an initial application was repeated 5 days later.
- They do not eradicate well-established infections when applied to actively sporulating lesions, but they do limit further spore production by approximately 80%.

Observations and rumors for the last few years suggest that the activity of these products is not quite was it used to be, and that we might be facing a similar "shift" in sensitivity (partial resistance) to them as we've encountered with the DMI fungicides versus powdery mildew. Ideally, this will be a focus of future research for someone.

In recent years, we've found that some of our newer DM-specific fungicides (particularly Revus/Revus Top and Zampro) have provided outstanding control of DM even under high disease pressure and relatively long (14-day) spray intervals. We do not have a good handle on their relative post-infection capabilities, and that would be nice for someone to determine. I have also been very pleasantly surprised by the consistently excellent control that we've obtained in these same trials over the last few years with the new product, LifeGuard, which acts as an inducer of natural plant resistance in other crops (many have claimed to do this on grapes, this appears to be the first one that actually does so). There's still plenty of work to do to look at the fine print on this one.

Figure 7. Phomopsis berry infection on cv. Niagara. Note advancement of the fungus from the pedicel (berry stem) into the berry itself near the top of the photo. Two additional diseased berries are visible at bottom left.

Phomopsis (Ph). Phomopsis is relatively uncommon on many *vinifera* and hybrid wine cultivars due to the management they receive, although these vines generally are susceptible to the disease. However, on native grapes (particularly those grown for the juice market), I have perhaps seen more losses over the years due to Phomopsis than any other disease. Niagaras, in particular, appear to be especially susceptible.

For nearly a decade, we conducted a series of studies on Ph in the Lake Erie region, with the invaluable collaboration of Rick Dunst at the Vineyard Lab in Fredonia and significant technical assistance from Mike Vercant, the crew of technicians led by Kelly Link, and Extension Educator Tim Weigle. Some of the major findings:

- The Ph fungus liberates its overwintering spores primarily during the period between early shoot growth and the early post-bloom period. Because there is no secondary spread of this disease, the danger of infection is over after that.
- Control of the total number of rachis infections improves as the number of fungicide sprays increases. However, most control of the girdling rachis infections (those that cause economic losses) is provided by a single spray applied at the 3- to 5-inch shoot growth stage, i.e., when the new clusters are first visible.
- Most control of berry infections (especially damaging on Niagara) is provided by these early sprays as well. This was surprising, since such sprays are about a month before bloom. However, berry infections usually are the result of the fungus expanding from the pedicel (berry stem) into the berry during the pre-harvest period **(Fig. 7)**. Thus, it appears that in many cases, these pedicel infections are occurring shortly after the new clusters first emerge, and protection is needed at that time.
- In two separate years, we obtained yield increases of >2 tons/acre in a high-yielding Niagara block with just a single spray of mancozeb timed during the 3- to 5-inch shoot growth stage. This was a result of controlling both the girdling rachis infections (which cause berries to drop before harvest) and infection of the berries themselves.

Sour Rot. Graduate student Megan Hall has just completed her project examining the causes and control of sour rot. (Entomologist Greg Loeb and members of his lab deserve recognition here for their critical collaborative contributions).

This work was recently described in detail *(See* **Defining and Developing Management Strategies for Sour Rot** *in Appellation Cornell Issue #30),* but the major findings were:

- The acetic acid (vinegar smell) production that gives sour rot its name is the culmination of a process that initially involves conversion of grape juice into ethanol by yeast (many capable of doing so are present in and on grapes everywhere), followed by its oxidation to acetic acid by a few specific bacteria.

- This process is greatly aided by the presence of *Drosophila* fruit flies. Indeed, classic sour rot symptoms, which include the breakdown of diseased berries and leakage of their contents, did not develop in controlled studies unless these flies were present along with the necessary yeast and bacteria.
- In the field, fruit flies carry the yeast and bacteria on their bodies and in their guts, and are responsible for spreading them and the disease that they cause as these insects move among clusters in the vineyard. However, using axenic ("sterile") flies in the laboratory, we found that these insects also have a major effect that is independent of microorganisms.
- In repeated vineyard trials, we obtained significant control of sour rot by spraying an insecticide (Mustang Maxx) for control of the flies after berries became susceptible to infection at 15°Brix (recognition goes to Wendy McFadden-Smith in Ontario for determining when berries become susceptible). Control was improved further when general antimicrobial compounds were applied with the insecticide, but antimicrobials without insecticide were generally not very effective.
- Less sour rot developed in a VSP training system than in a high-wire cordon system, probably a result of the improved ventilation around the berries in the former.

Wayne Wilcox and graduate student Megan Hall

As a final sign-off, I'd like to thank the many students, technicians, faculty, and extension educators with whom I've worked over the years but did not get an opportunity to mention specifically in the text above. And most of all, I'd like to thank members of multiple segments of the grape industry here in New York and beyond, who have been so supportive of this program over the years. It's been a dream job, and I'll miss it (But not enough to reconsider retirement!).

Additional Reading:

Austin, C. and W. Wilcox. 2010. Heat and UV Radiation from Sunlight Exposure Inhibit Powdery Mildew. Research Focus 2010-2, Appellation Cornell Issue #2. April, 2010. Cornell University.

Moyer, M., D. Gadoury, and R. Seem. 2011. Variable Eastern Weather Influences Powdery Mildew Severity . Research Focus 2011-2, Appellation Cornell Issue #6. April 2011. Cornell University.

Gadoury, D. , R. Seem and M. Moyer 2012. Climate, Duration of Bloom, and the Window of Risk for Grapevine Diseases. Research Focus 2012-3, Appellation Cornell Issue #11. August 2012. Cornell University.

Wilcox, W. 2016. *Botrytis* Bunch Rot: A Disease Requiring Integrated Control. Research Focus 2016-4, Appellation Cornell Issue #26. November, 2016. Cornell University.

Hall, M. and W. Wilcox. 2017. Defining and Developing Management Strategies for Sour Rot**.** Research Focus 2017-3, Appellation Cornell Issue #30. August 2017. Cornell University.

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