
Research News from Cornell's Viticulture and Enology Program Research Focus 2017-3

# Research Focus

## Defining and Developing Management Strategies for Sour Rot

**Megan Hall[1,2], Gregory Loeb[3], and Wayne Wilcox[2,4]**

[1]Graduate Research Assistant, [2]Section of Plant Pathology and Plant-Microbe Biology, School of Integrative Plant Science, Cornell University, NYS Agricultural Experiment Station, [3]Professor, Dept. of Entomology, Cornell University, NYS Agricultural Experiment Station, [4]Professor

*Sour rot disease develops because of berry wounds, ethanol-producing yeast, acetic acid bacteria, and fruit flies. Drosophila sp. fruit flies play a key role in the development of the disease.*

Sour rot, a late-season bunch rot, is an increasing concern, particularly among growers of tight-clustered or thin-skinned grape varieties. It is characterized by brownish, oxidized berries and a strong vinegar aroma. Its causes and management in the field have been poorly understood.

Over the past four years, we have studied sour rot in the laboratory and field to determine which specific organisms and conditions are needed for it to develop. We found that ethanol-producing yeast, acetic acid bacteria, and *Drosophila* fruit flies are all essential for sour rot to develop and spread. Spray trials assessing control with antimicrobial products, insecticides, or both in combination showed that the combination program was most effective. An insecticide alone provided significant control in two of the three years in one trial, whereas antimicrobial products without an insecticide usually provided relatively little control.

### Key Concepts

- *Sour Rot* is sometimes used as a catch-all term to refer to unidentified late-season bunch rots that develop in tight-clustered or thin-skinned varieties.
- The causes and organisms associated with sour rot have been poorly understood.
- Our project defined sour rot as a combination of several elements: oxidized skins (brown), odor of acetic acid, and association with *Drosophila* fruit flies.
- Sour rot-affected berries collected in the field contained significant amounts of ethanol (produced by *Saccharomyces* yeasts) and acetic acid (produced by bacteria).
- Experimental inoculation in the laboratory with these microbes alone was not sufficient to produce sour rot symptoms.
- Sour rot symptoms developed only when *Drosophila* fruit flies were added to experimental inoculations.
- Field spray trials over three years with antimicrobials targeting the yeast and bacteria alone provided modest reductions in sour rot severity.
- Including insecticides targeting *Drosophila* fruit flies dramatically reduced sour rot severity.
- *Drosophila* fruit flies play an important role in the development and spread of sour rot.
- High cordon-trained *Vignoles* had higher severity of sour rot than midwire cordon-trained vines with vertical shoot positioning in 2014, 2015 and 2016.
- Management of sour rot involves controlling both the microbes and the *Drosophila* fruit flies.

***Sour rot*** is a term often used imprecisely to refer to late-season bunch rots that are not easily identified. This has posed problems for growers and researchers alike. To successfully manage a disease, it's important to identify the organisms involved, and how they interact with the environment to produce the disease. Our research over the past four years has been focused on developing a more precise definition, guided by a fundamental question and related goal: *What causes sour rot and how do we control it?*

In this project, we have defined sour rot as a specific syndrome, characterized by the oxidation of the berry skin and the smell of acetic acid (vinegar) emanating from diseased grapes. We also note that in the field, such berries are almost always associated with high populations of *Drosophila* fruit flies.

Although it occurs sporadically, sour rot has been reported from throughout North America and worldwide following periods of high-humidity or precipitation in the final few weeks before harvest. Sour rot typically develops rapidly on thin-skinned, tight-clustered grape varieties during the pre-harvest period (work done by Dr. Wendy McFadden-Smith and colleagues in Ontario shows that susceptibility begins at approximately 15°Brix). This is particularly frustrating for growers who have successfully controlled other diseases throughout the growing season, only to make it nearly to harvest and to be faced with a destructive disease for which there are no reliable management options.

**Wounds are important**. Wounds originating from splitting of the skin as berries expand or from their separation from the pedicel as berries press up against one another, are required for the development of sour rot. They facilitate entry of the microbes and insects that are causal components of the sour rot complex. They also allow oxygen to be introduced into the berry, which is necessary for the conversion of ethanol, first produced by endogenous and introduced yeasts, to acetic acid by bacteria within the grape berry. In turn, the volatilization of ethanol and acetic acid attract specific insects, particularly *Drosophila* fruit flies, that feed on the yeast and bacteria producing these compounds.

In our four-year-study we have developed a definition of sour rot, a chemical management program, and identified significant differences in disease severity related to trellising systems.

**Measuring ethanol and acetic acid in field samples**. While the term sour rot implies the presence of vinegar, the amount of acetic acid within diseased samples has been poorly characterized. We collected berries from sour rot-affected clusters from seven Finger Lakes vineyard blocks in 2014 and nine in 2015, and used High-Performance Liquid Chromatography (HPLC) to analyze samples for both ethanol and acetic acid content. The ethanol content of the berries averaged 1.12 and 1.16 g/L in in 2014 and 2015, respectively, while the acetic acid content was 0.95 and 2.20 g/L in these same years (**Figure 1**).

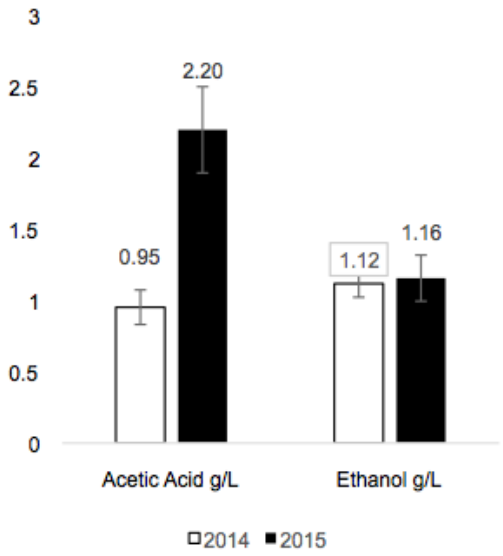


**Figure 1**. *Mean acetic acid and ethanol content in g/L of three-grape samples from four sour rot-infected clusters from seven vineyards in 2014 and nine vineyards in 2015, collected within the Finger Lakes AVA.*

**Yeast and bacteria recovered from field samples**. From these same vineyard samples, we washed surface microbes from the outside of symptomatic grapes, macerated the berries to express juice, and plated them out on two different media, semi-selective for yeast and acetic acid bacteria respectively. This resulted in over 1300 individual microbial isolates, which were grouped into nine broad morphological categories, four of which contained over 90% of the recovered microbes.

Sequencing of these samples using both fungal and bacterial primers revealed two *Saccharomyces cerevisiae* yeast strains and two bacteria, identified as *Gluconobacter spp.*, an acetic acid bacterium, and *Rahnella spp.*, a ubiquitous environmental bacterium. *Rahnella spp.* are commonly found in soil and water samples but are not associated with acetic acid production and are not considered plant pathogens.

**Causal agent determination**. Using *Vitis vinifera* cv. Red Globe berries, our lab conducted experiments to fulfill Koch's postulates, the standard procedure used by plant pathologists to prove that a microorganism (or microorganisms) associated with a disease is/are, indeed, its cause. We first wounded the berries, then inoculated them with each combination of the four microbes most commonly recovered from sour-rotted berries, both individually and in pairs. The samples were either exposed to axenic fruit flies (*Drosophila melanogaster*, which were reared in sterile media, rendering them devoid of gut and surface microbiota), or not exposed to fruit flies.

Each treatment was rated for disease symptoms at the end of 8 days using a 0-4 rating scale, in which 0 = no visual or olfactory symptoms of sour rot; 1 = some necrosis but no olfactory symptoms; 2 = significant necrosis but no olfactory symptoms; 3 = significant necrosis and the smell of

**Figure 2.** *Laboratory inoculations with microbes alone (left) failed to produce sour rot symptoms. Addition of Drosophila melanogaster (right) was necessary to reproduce symptoms observed in the field.*
Photos by Megan Hall

acetic acid; and 4 = complete necrosis of the berry including oozing of the inner pulp, partnered with a strong smell of acetic acid. The berries were then macerated and half of the expressed juice was plated onto semi-selective media to isolate the organisms present within. The other half was analyzed for ethanol and acetic acid content via HPLC.

Based upon visual and olfactory symptoms observed in the field, namely oxidation of the berry skin partnered with the smell of acetic acid, we defined inoculated fruit as having sour rot when they had an average rating of 3 or greater on the 0-4 rating scale, and the mean acetic acid content within a particular treatment was greater than 0.83 g/L, which was determined by taking the mean of the 2014 field samples minus the standard error of that sample set. Using these criteria, the following combinations of organisms caused sour rot symptoms, but only in the presence of axenic fruit flies:

- *Gluconobacter spp.*
- *S. cerevisiae Strain 1*
- *S. cerevisiae Strain 2*
- *Gluconobacter spp. + S. cerevisiae S1*
- *Gluconobacter spp. + S. cerevisiae S2*
- *S. cerevisiae S1 + S. cerevisiae S2*
- *S. cerevisiae S1 + Rahnella spp.*
- *S. cerevisiae S2 + Rahnella spp*

**Fruit flies necessary to produce sour rot symptoms**. Berries in treatments that were not exposed to flies had neither sufficient acetic acid levels nor disease ratings high enough to be considered symptomatic of sour rot, nor did *Rahnella spp*. on its own in the presence of fruit flies cause sour rot symptoms (**Figure 2**). Sequencing of organisms recovered from the diseased berries revealed the same organisms used in the initial inoculation.

**Additional microbes tested**. To explore whether additional organisms could cause disease symptoms, we repeated the inoculation experiment on Red Globe berries using isolates of the following species obtained from American Type Culture Collection (ATCC), to represent a wider variety of yeast and acetic acid bacteria and combinations thereof:

- *S. cerevisiae*
- *H. uvarum*
- *P. kluyveri*
- *A. aceti*
- *G. oxydans*
- *S. cerevisiae x A. aceti*
- *S. cerevisiae x G. oxydans*
- *H. uvarum x A. aceti*
- *H. uvarum x G. oxydans*
- *P. kluyveri x A. aceti*
- *P. kluyveri x G. oxydans*

Using the criteria described above, only *S. cerevisiae* + *A. aceti*, *S. cerevisiae* + *G. oxydans*, *P. fermentans* + *A. aceti* and *P. fermentans* + *G. oxydans* caused sour rot symptoms, but only in the presence of axenic fruit flies.

**Inoculation experiments with wild-type Drosophila**. In an additional set of inoculation experiments on *V. vinifera* cvs. Cabernet franc, Chardonnay and Red Globe, using wild type rather than axenic fruit flies, two additional organisms were included: the bacterium *Lactobacillus brevis*, due to its ubiquity on the surface of intact grape berries near harvest, and the filamentous fungus *Aspergillus niger*, which has long been suggested as a cause of sour rot, but with no supporting experimental evidence. The following single organisms and combinations were examined:

- *Saccharomyces cerevisiae*
- *Hanseniaspora uvarum*
- *Pichia kluyveri*
- *Acetobacter aceti*
- *Gluconobacter oxydans*
- *Aspergillus niger*
- *Lactobacillus brevis*
- *S. cerevisiae x A. aceti*
- *S. cerevisiae x G. oxydans*
- *S. cerevisiae x A. aceti x G. oxydans*
- *S. cerevisiae x L. brevis*
- *A. niger x A. aceti*
- *A. niger x A. aceti x G. oxydans*
- *A. niger x G. oxydans*
- *H. uvarum x A. aceti*
- *H. uvarum x G. oxydans*
- *H. uvarum x A. aceti x G.oxydans*
- *P. kluyveri x A. aceti*
- *P. kluyveri x G. oxydans*
- *P. kluyveri x A. aceti x G. oxydans*

Across all three cultivars, the only combinations of organisms that caused sour rot as per our criteria were:

- *Aspergillus niger x Gluconobacter oxydans*
- *Hanseniaspora uvarum x Acetobacter aceti*
- *Hanseniaspora uvarum x Acetobacter aceti x Gluconobacter oxydans*
- *Pichia kluyveri x Acetobacter aceti*
- *Pichia kluyveri x Gluconobacter oxydans*
- *Saccharomyces cerivisiae x Acetobacter aceti*
- *Saccharomyces cerevisiae x Gluconobacter oxydans*

These combinations produced sour rot symptoms only on berries also exposed to wild type *Drosophila* fruit flies, which carry their own microbiota. When inoculated berries were not also exposed to the flies, sour rot symptoms did not develop.

**Three components essential for sour rot disease development**. Based upon the result of these various inoculation experiments, it appears that multiple combinations

of microorganisms can cause sour rot symptoms. However, the requisite components appear to be the presence of (i) yeast, which first produce ethanol from the juice of the affected grapes; (ii) acetic acid bacteria, which convert the ethanol to acetic acid; and (iii) *Drosophila* fruit flies. None of these elements cause disease symptoms on their own.

In nature, yeast and acetic acid bacteria may originate from several sources: the outside of healthy berries, albeit in low numbers; the inside of healthy berries (in other studies not reported here, we have repeatedly isolated various non-*Saccharomyces* yeasts such as *Pichia spp*. from the inside of healthy berries, in addition to acetic acid bacteria on occasion); and Drosophila fruit flies, which are widely reported to contain both yeast and acetic acid bacteria in their guts.

Our results with axenic *Drosophila* also show that whereas these insects may vector the causal microbes either passively on the outside of their bodies or by transferring gut microbes during feeding, they are also making a vital non-microbial contribution to the development of sour rot, the nature of which is still unknown. Thus, sour rot control programs in the vineyard ideally should include measures targeting both microbes and these insects.

**Chemical control trials**. In three spray trials conducted in 2013, 2015 and 2016 in Geneva, NY, we applied several combinations of antimicrobials and insecticide – alone and in combination - to a Vignoles (interspecific hybrid variety) vineyard to test the effect of these treatments on sour rot incidence and severity.

In each trial, alternate rows were sprayed with an insecticide (Delegate in 2013 or Mustang Max in 2015-2016) or left untreated. Then one- or two-panel plots were treated with antimicrobial materials (Potassium metabisulfite, Kocide 3000, OxiDate 2.0, Oxidate or Fracture) at various timings and rates (see treatment list in **Table 1** with results). Please note that potassium metabisulfite (KMS), a common disinfectant in the winery is **not registered for use in the field** but was included in these tests as a "proof of concept".

Insecticides were applied weekly when fruit reached 15.0 °Brix. The start of antimicrobial treatments varied and timing is listed in Table 1 as i) pre-symptoms – weekly starting at 15 °Brix; ii) at symptoms – weekly starting when sour rot symptoms started to be visible; iii) with OxiDate 2.0 treatments, starting after first rain following 15.0 °Brix, iv) OxiDate 2.0 weekly following increase in maximum daily dew point over 3 days; v) No treatment.

**Results**. In 2013, applying both antimicrobials and insecticide provided significant control of sour rot, with a reduction in disease severity (% cluster area diseased) of more than 50% over the untreated control. (**Table 1**, **Table 2**). Those vines that were treated solely with antimicrobial sprays, however, did not see a significant reduction in severity, nor did the treatment in which only insecticide was applied.

2015 had significantly greater sour rot pressure, with an average of 29% on vines receiving no insecticide or antimicrobial, in comparison to 16% in 2013. In contrast to 2013, the insecticide alone provided significant control (57%) without the addition of an antimicrobial. Antimicrobial-only treatments were less effective than the insecticide-only treatment. The level of disease control increased significantly in those panels in which both antimicrobials and insecticide treatments were applied weekly starting *before the onset of symptoms*. Where the start of antimicrobials was delayed until the onset of symptoms, antimicrobials did not provide significant control beyond that provided by the insecticide.

Sour rot severity on untreated vines in 2016 was comparable to that in 2015, and again, there was significant control (40%) with the insecticide applied without the addition of an antimicrobial (**Figure 3**). Once again, we saw significant control in those treatments in which anti-

**Table 1**. Mean percent disease control over the untreated control in each year and the mean percent control across all years in which that treatment was administered.

| Treatment | Insecticide | 2013 | 2015 | 2016 | Mean |
|---|---|---|---|---|---|
| Control | No | 0% | 0% | 0% | 0% |
| | Yes | 9% | 57% | 40% | 35% |
| KMS 0.5% Pre-Symptoms[a] | No | 11% | | | 11% |
| | Yes | 30% | | | 30% |
| KMS 1.0% Pre-symptoms[a] | No | 12% | 0% | 11% | 8% |
| | Yes | 52% | 76% | 66% | 65% |
| KMS 1.0% at symptoms[b] | No | 8% | 34% | | 21% |
| | Yes | 46% | 46% | | 46% |
| Kocide, Pre-symptoms[a] | No | 10% | | | 10% |
| | Yes | 54% | | | 54% |
| Fracture Weekly Pre-symptoms[a] | No | | 14% | 32% | 23% |
| | Yes | | 73% | 52% | 63% |
| Fracture Once at 15° Brix | No | | 12% | | 12% |
| | Yes | | 58% | | 58% |
| Fracture Weekly at Symptoms[b] | No | | 32% | 15% | 23% |
| | Yes | | 56% | 44% | 50% |
| Oxidate 2.0 Weekly 1% Pre-symptoms[a] | No | | 31% | 3% | 17% |
| | Yes | | 84% | 55% | 69% |
| Oxidate 2.0 Weekly 1.0% at symptoms[b] | No | | 36% | 0% | 18% |
| | Yes | | 40% | 53% | 47% |
| Oxidate 2.0 Weekly 1.0% following first rain after 15B | No | | | 27% | 27% |
| | Yes | | | 33% | 33% |
| Oxidate 2.0 Weekly 1.0% following increase in max daily dew point over 3 consecutive days | No | | | 47% | 47% |
| | Yes | | | 33% | 33% |

[a] *Weekly treatments started at 15.0 °Brix*

[b] *Weekly treatment started when first sour rot symptoms observed*

microbials and insecticides were both applied starting before the onset of symptoms, and less control when two of the three antimicrobial treatments were delayed until symptom onset (**Table 1**).

These three years of chemical control trials demonstrated the importance of insecticide sprays in controlling sour rot, and the additive or synergistic effect when antimicrobial sprays were also applied before the onset of symptoms. In every year, applying KMS weekly beginning pre-symptoms in conjunction with an insecticide provided an average 65% control over the untreated control, and in 2015 and 2016, using OxiDate 2.0 in conjunction with Mustang Maxx starting weekly before the onset of symptoms provided an average 69% control. In two of the three years of the chemical trial, there was also a significant effect of the insecticide alone. For growers deciding whether to apply only an insecticide or antimicrobial product, the insecticide appears to be the more important component (**Table 2**).

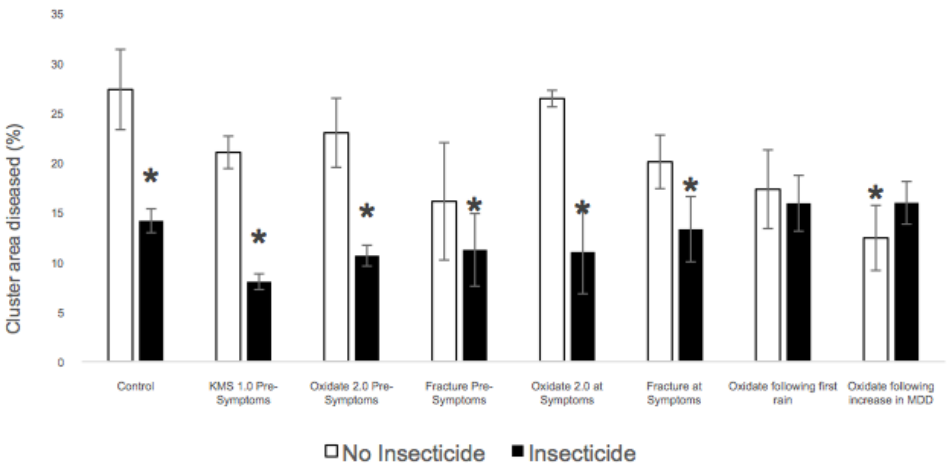


**Figure 3**. *Sour rot severity in a vineyard block of Vitis interspecific hybrid cv. Vignoles in Geneva, NY in 2016 as a function of antimicrobial and insecticide treatments.*

Also noteworthy is that regular applications of antimicrobials and initiating them before the onset of symptoms was more effective than a limited number of applications of antimicrobials after symptoms appeared. While we did not experiment with the application of insecticides after the initiation of symptoms, it is likely we would have seen a similar effect. Once disease symptoms were spotted in the vineyard, sour rot was significantly harder to control.

However, it's also important to recognize that in our trials we were treating a relative handful of rows embedded within a 1.5-acre solid block of Vignoles, and none of the other rows received these sour rot treatments although the disease developed within them. Thus, our treated rows were surrounded by nearly 1.5 acres of vines with increasingly higher levels of flies and sour rot microorganisms as the epidemic continued to build in each year. This would not be the case in a commercial vineyard where the entire block was treated, and a more limited spray program might be enough to stop disease progression if there was not a constant influx of flies and microorganisms from untreated vines all around. Indeed, this is exactly what we saw in the commercial block we monitored in 2015, as discussed below.

**Training system effects**. In a commercial vineyard of *Vitis* interspecific hybrid cv. Vignoles in Branchport, NY, one block is divided into 14 rows of vines trained in a vertical shoot position (VSP) system and 14 adjacent rows of vines are trained to a high wire (HW) cordon system. Significant sour rot severity had been observed in the vineyard block in previous years, and our goal was to study whether or not training system had a significant effect on sour rot development. In 2014 through 2016, one vine was selected in each of 20 rows, 10 in the VSP section and 10 in the HW section of the block. Total cluster counts were taken and following the first sighting of sour rot symptoms in the vineyard, disease ratings were taken every 3 to 4 days until harvest.

In all three years of the study, there was significantly more sour rot at harvest in those vines trained to a HW trellis system than to the VSP system. Sour rot severity averaged 27% in the HW and 16% in the VSP block (**Figure 4, 5, and 6; see next page**). In the wetter years of 2014 and 2015, there was significantly more sour rot in the HW-trained vines at every time point.

This study served not only to examine the differences between training systems but also to document the rapid progression of disease severity, as it increased steadily in both training systems over the observed time leading up to harvest. In 2014, sour rot severity increased from 21% to 35% in the HW and 13% to 18% in the VSP system over just the final 7 days before harvest (**Figure 5**).

**Table 2.** P-values associated with percent disease severity and percent disease incidence of each effect included in the mixed-effects model used to analyze the results of the chemical control trials in 2013 – 2016.

| | Antimicrobial | | Insecticide | | Antimicrobial*Insecticide | |
|---|---|---|---|---|---|---|
| | % Cluster area[a] | % Diseased clusters[b] | % Cluster area | % Diseased clusters | % Cluster area | % Diseased clusters |
| | $p$[c] | $p$ | $p$ | $p$ | $p$ | $p$ |
| **2013** | <0.0001* | 0.0009* | <0.0001* | 0.0135* | 0.0079* | 0.067 |
| **2015** | 0.817 | 0.166 | 0.0096* | <0.0009* | 0.541 | 0.538 |
| **2016** | 0.214 | 0.591 | 0.0161* | 0.0197* | 0.0172* | 0.851 |

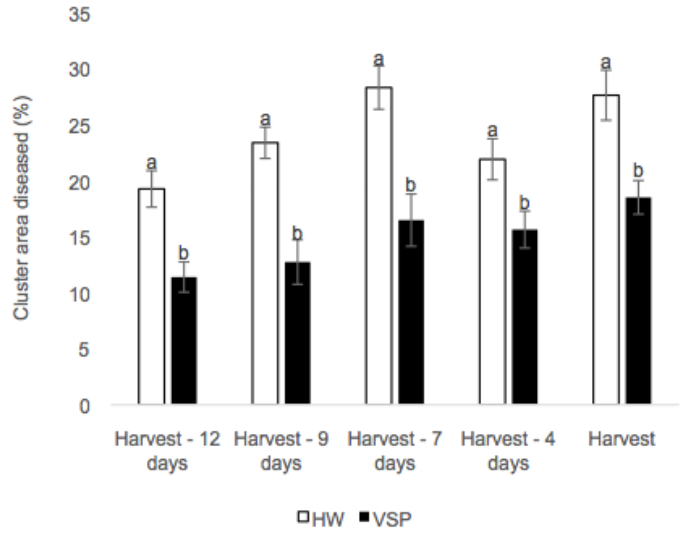


**Figure 4**. *Sour rot severity in a commercial vineyard block of Vitis interspecific hybrid cv. Vignoles in Branchport, NY in 2015 as a function of the two training systems in the block, High Wire (HW) and Vertical Shoot Positioning (VSP). Means not followed by a common letter are significantly different according to the Tukey-Kramer HSD test (p = 0.05).*

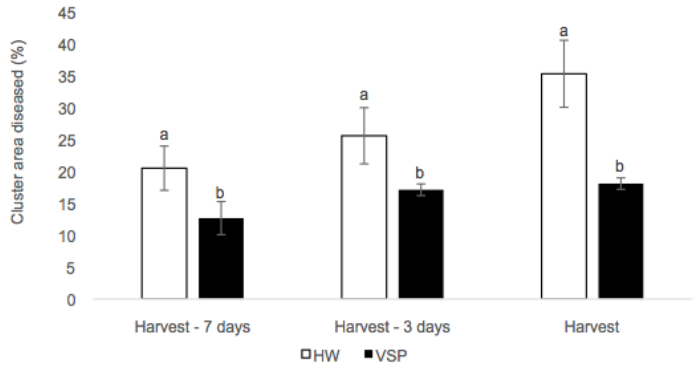


**Figure 5.** *Sour rot severity in a commercial vineyard block of Vitis interspecific hybrid cv. Vignoles in Branchport, NY in 2014 as a function of the two training systems in the block, High Wire (HW) and Vertical Shoot Positioning (VSP). Means not followed by a common letter are significantly different according to the Tukey-Kramer HSD test (p = 0.05).*

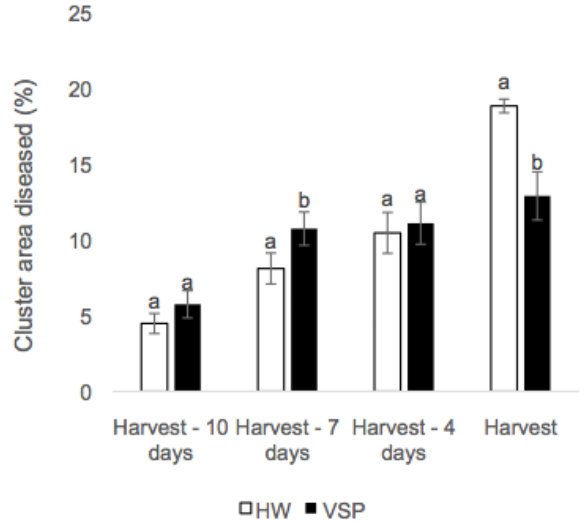


**Figure 6.** *Sour rot severity in a commercial vineyard block of Vitis interspecific hybrid cv. Vignoles in Branchport, NY in 2016 as a function of the two training systems in the block, High Wire (HW) and Vertical Shoot Positioning (VSP). Means not followed by a common letter are significantly different according to the Tukey-Kramer HSD test (p = 0.05).*

In 2015, the vineyard owner applied both KMS at a rate of 1.0% and Mustang Maxx to the entire vineyard block 6 days before harvest (**Figure 4**). The exponential increase in disease severity recorded throughout the monitored period in both 2014 (**Figure 5**) and 2016 (**Figure 6**) and prior to the spray application in 2015 was not observed after the sprays were applied, as it never progressed beyond the level observed just prior to treatment.

**What is sour rot and how do we manage it**? The results of our studies have led us to understand that the sour rot complex is a dynamic system, involving yeast, acetic acid bacteria and *Drosophila* fruit flies. The species of yeast can vary, as it can for the acetic acid bacteria and fruit flies (we obtained similar results in some parallel studies comparing the effects of *D. melanogaster* and *D. suzukii*, the spotted wing *Drosophila*), yet all three components must be present in order for symptoms to develop.

The collection of samples throughout the Finger Lakes AVA has shown that there are multiple yeast species present on and in grapes that can initiate the production of ethanol. But the addition of a wound site, partnered with the introduction of bacteria and fruit flies is what causes the accumulation of acetic acid and the necrosis that we associate with sour rot symptoms.

We learned that looking for sour rot symptoms or measuring acetic acid content alone could not lead us to a definition, but using both could. This approach to defining sour rot means we are assessing both visual and olfactory symptoms, but not relying solely on our ability to spot necrosis or smell acetic acid. Quantification of acetic acid in a research mode has allowed us to establish whether or not candidate organisms within the disease complex have, following inoculation, successfully generated the characteristic acetic acid required to satisfy our definition of sour rot.

**Management**. Managing sour rot, in turn, has to include targeting multiple organisms, which is why the use of antimicrobials and insecticide can provide the greatest level of disease control. Targeting only the microbes on the grape surface does not allow for the control of those already within the grapes, at the wound sites that may not be easily accessible by applied sprays, or those subsequently delivered to wounds by fruit flies. In our trial this approach was only modestly effective. Targeting fruit flies, however, did significantly reduce disease severity, and we have shown that these insects play an important non-microbial role in the development of sour rot in addition to whatever role they play as vectors of the responsible microbes.

We have also documented the significant effect of training systems on sour rot severity. Whereas the trellis system is not something that is easily modified, being aware that canopy architecture can have a significant positive or negative impact on disease development is an important reminder of the myriad ways in which canopy management can impact the quality of the resulting crop. Sus-

ceptible hybrid varieties such as Vignoles are commonly grown on HW systems, and understanding that this system is more conducive to sour rot development than VSP should encourage increased vigilance concerning its management in relevant blocks.

**Treatments targeting both insects and microbes**. Our results suggest that in addition to relevant canopy management, chemical treatments utilizing both broad-spectrum antimicrobials and, particularly, insecticides targeting *Drosophila spp*. may provide significant control of this disease. Additional trials under commercial or large-plot conditions should help define the most efficient timings to balance the competing desires to minimize spray numbers while maximizing control, although our existing data suggest that control is likely to be maximized by initiating sprays before an epidemic is in progress. It is also important to note that these studies have been conducted with susceptible cultivars and in a climate favorable to the development of severe disease symptoms. While we did not specifically study cultivars and climatic variables, management recommendations may vary for vineyards with thicker-skinned, looser-clustered cultivars in a less conducive environment.

This understanding of the sour rot complex is not only applicable to New York State grape growers but can be valuable to growers worldwide who experience sour rot as a challenge in their vineyards. We now understand that the yeast and bacteria necessary for the onset of symptoms can vary, and that oftentimes these organisms are already present within or on the grape surface, waiting for a wound site to provide an entry point for *Drosophila*. This complex is unique because we are not targeting a single causal organism, but we now have a more comprehensive understanding of how it develops, and in turn, how to manage it.

**For additional information:**

McFadden-Smith, W. and W.D. Gubler. 2015. Sour Rot. in: Compendium of Grape Diseases, Disorders, and Pests, 2nd Ed. W. F. Wilcox, W. D. Gubler, and J. K. Uyemoto, eds. APS Press, St. Paul, MN. 232 pp.

**Acknowledgement**. We would like to extend a special thanks to Finger Lakes grape growers for allowing us the use of their vineyards for field trial. This project was funded by the New York Wine and Grape Foundation, the Dyson Fund and Specialty Crop Block Grant C200834 through the New York Dept. of Agriculture & Markets.

Photo by Megan Hall

*Megan Hall is a doctoral candidate in the Section of Plant Pathology and Plant-Microbe Biology, School of Integrative Plant Science based in Geneva, NY.*

*Gregory Loeb is Professor in the Department of Entomology, College of Agriculture and Life Sciences in Geneva, NY.*

*Wayne Wilcox is Professor in the Section of Plant Pathology and Plant-Microve Biology, School of Integrative Plant Science in Geneva, NY.*