Washington State Grape and Wine Research Program

FINAL REPORT - SUMMARY

Project Title: Monitoring and Mapping Grape Powdery Mildew Fungicide Resistance and Crown Gall Incidence in Washington Vineyards

Principle Investigator: Dr. Michelle M. Moyer, Washington State University

Summary:

This two-part project collected baseline survey data on two important issues in Washington wine grape production: 1) the presence of fungicide resistance in grape powdery mildew to one of our main class of synthetic fungicides, and 2) continued outbreaks of crown gall in newly planted vineyards despite recent industry-wide educational efforts on the importance of planting certified vines.

The development of fungicide resistance results in substantial economic loss related to fungicide application labor costs and unmarketable fruit . Working with a national team, we have developed a rapid diagnostic test to determine the presence of a genetic mutation that confirms resistance to the strobilurin (QoI, FRAC 11) fungicides to the grape powdery mildew fungus. We coupled this rapid testing tool with improved scouting and collections methods. The key outcome from this objective is the confirmation that fungicide resistance is here and is widespread. While fungicide resistance was a likely culprit in the wide-spread disease outbreaks seen in recent years, other factors that contribute to program failure and fungicide resistance selection were noticeable. These factors include: poor spray timing, lack of fungicide rotation, and poor sprayer application. To effectively manage fungicide resistance in grape powdery mildew, we will not only need to focus on chemical product stewardship, but also re-focus on product application and cultural approaches to reduce disease pressure.

Grapevine crown gall, a serious disease in northern climates, can be a limiting factor to successful vineyard establishment. Protocol 2010, which is the foundation for the vine certification process in the US, has approaches that reduce the crown gall pathogen in vines. However, not all vines on the market are certified, and recent (last 15 years) expansion of the industry resulted in wide-spread planting of vines from many sources. It became very clear through this study that many growers are not aware of what "certified" means for planting materials. For most of our surveyed sites, people assumed that the nursery was the certification unit, not the planting material (inaccurate assumption). It was also clear in our scouting efforts that, crown gall does serve as an indicator for site appropriateness (i.e., risk of cold damage) for wine grapes. While this was not always a welcomed observation, sites suffering from extreme levels of crown gall were often planted poor locations prone to cold damage. Typically, poor site selection was generally coupled with the choice to use non-certified vines. In these recent expansions, the choice to plant soon was the primary driver for material selection, rather than the choice to plant "clean".

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Project Title: Monitoring and Mapping Grape Powdery Mildew Fungicide Resistance and Crown Gall Incidence in Washington Vineyards

Project Duration: 3 years, FY18-20, 1 July 2017- 30 June 2020

Principal Investigator/Cooperator(s):

PI Name:	**Michelle M. Moyer**	**Cooperator Name:**	**Dr. Walt Mahaffee**
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Objective(s) and Experiments Conducted to Meet Stated Objective(s):

Effective management decisions can only be made when baseline information regarding the efficacy of current management options is available. This project was designed to address two such emerging (and re-emerging) issues that challenge our current vineyard disease management status quo. These issues are: 1) The development of fungicide resistance in grapevine powdery mildew to our most widely used fungicide group; and 2) Crown gall outbreaks in newly established vineyards. Without knowing the prevalence of fungicide resistance in our region, we cannot mitigate crop loss due to spray program failure. Assuming that "certified" means crown gall-free (or expecting that it does) places us at a disadvantage in proactively managing outbreak-prone vineyards. The objectives designed to address these concerns are outlined below.

Objective 1 - *Monitor and map the incidence of fungicide resistance in powdery mildew populations in commercial vineyard settings*. There were three sub-components to this objective. The first two are focused on sampling, monitoring, and optimizing sampling techniques for powdery mildew. The third is focused on working with growers to adjust spray programs and to monitor what impact those adjustments have on fungicide resistance in powdery mildew.

This project was the starting point (and matching funds) for a larger, federally funded project on grape powdery mildew fungicide resistance. That project was funded by the United States

Department of Agriculture – National Institute for Food and Agriculture – Specialty Crop Research Initiative Award No. 2018-03375 titled "FRAME: Fungicide Resistance Assessment, Mitigation and Extension Network for Wine, Table, and Raisin Grapes," and is funded from September 2018 until August 2022. For additional information on that complementary project, please visit: https://framenetworks.wsu.edu/.

Objective 1a - Initial sampling and mapping. In collaboration with the USDA-ARS in Corvallis, OR, we used a qPCR method to identify a SNP (single-nucleotide polymorphism) mutation that is associated with a resistant phenotype in *Erysiphe necator* (Falacy *et al.*, 2007*;* Miles *et al.* 2020). This SNP (called G143A) is a mutation that interferes with an inhibitor binding site of cytochrome b gene (associated with electron transfer in the mitochondria of a cell). When that inhibitor binding site is changed, strobilurin (QoI; FRAC 11) fungicides can no longer interact with it – and it's that interaction that makes the fungicide effective. No interaction results in lack of activity of the fungicide against the pathogen, and thus, a resistant phenotype.

Initially, we planned on using this genetic test to evaluate the occurrence of this mutation in chasmothecia (overwintering structure of grape powdery mildew), to potentially provide a prediction of potential fungicide resistance occurrence the following season. Unfortunately, chasmothecia collection was less than optimal in grower-submitted samples. Additionally, chasmothecia are sexual structures of the fungus, making it difficult to translate how the presence of the mutation leads to field-level resistance. Note, an individual fungal isolate can carry the resistance gene and be resistant to the fungicide, however, that does not translate to field-level fungicide control failure. For field-level control failures, most to all of the individuals in the field need to be resistant.

The basic design of this project was a survey. During winter meetings, growers were given various sampling kits (see Objective 1b below) to use over the course of the following growing season when powdery mildew was observed in their vineyard. We also did our own routine sampling (spatially, and temporally) within research blocks and neighboring vineyards. Overall, a survey-based sampling technique does have a bias since samples are often collected from sites experiencing high levels of powdery mildew (i.e., program failures). Despite this bias, it is still helpful in identifying the potential reasons for those failures (i.e., fungicide resistance). Samples were typically submitted from June until September and shipped to USDA-ARS in Corvallis for DNA extraction and processing. Sample results were typically returned to the grower within 2 weeks (provided return contact information was included). Starting in 2019, when sample results were returned, participating growers were also given a "decision tree" to help them adjust spray programs according to their sample results. This decision tree can be found at: https://framenetworks.wsu.edu/grower-information/.

Objective 1b - Testing alternative mildew sampling methods. This objective was supporting work funded by other entities (American Vineyard Foundation), that looked at different ways to more effectively collect powdery mildew from vineyards. This objective evaluated the use of different direct-colony sampling strategies (**Figure 1**) and the potential of indirect sampling methods (i.e., swabbing from equipment, workers gloves)for monitoring both the presence of powdery mildew, and the presence of fungicide-resistance conferring mutation. First, sampling methods were evaluated to determine if they could capture enough powdery mildew to produce testable genetic material (Falacy et al. 2007). Once that was optimized, we used the same sampling methods to determine if we could detect resistance alleles in the fungus.

Figure 1 – Direct colony sampling methods were evaluated. These methods allowed for quick field sampling, where the collected powdery mildew could be easily transported to a lab for further testing.

While we also initially planned on using aerial sampling methods, we quickly determined that the use of spore trapping was problematic due to sample dilution. It is hard to get an adequate sample size (i.e. enough powdery mildew spores) with early season aerial trapping. In addition, some of our preliminary evidence from evaluating historical spore trapping vs. in-canopy sampling methods indicated that resistant isolates carrying the G143A mutation may have reduced sporulation, and thus, would not necessarily be adequately represented in aerial samples. That allowed us to focus on more direct-canopy sampling methods, and ultimately settled on those methods which allowed for maximum sampling potential (i.e., swabbing workers gloves or hands**; Figure 2 – next page**). A complete description of the process for swabbing can be found at: https://framenetworks.wsu.edu/grower-information/.

Figure 2 - The cotton swab method, which can be used directly on powdery mildew colonies, or worker gloves, is now the preferred sampling method. For written and video tutorials, visit: https://framenetworks.wsu.edu/grower-information/

Objective 1c - Measuring impact of mitigation strategies on fungicide resistance in powdery mildew populations. The intent of this objective was to identify growers who had known FRAC 11 fungicide resistance, and then follow the incidence of fungicide resistance in their vineyards in 2018 and 2019. In those monitored years, the growers would have to agree to not use an additional FRAC 11 fungicide and would have to agree to share spray records with us. Similar to the above objectives, this was a survey-style monitoring program. Growers had to voluntarily allow routine evaluation of previously identified blocks and agree to provide access to their spray records. This monitoring was completed in a few select vineyards with documented FRAC 11 fungicide resistance in the powdery mildew population, including of our own research vineyard at WSU Prosser. Additionally, we also monitored powdery mildew populations in vineyards not regularly receiving powdery mildew fungicide sprays (i.e., Concord blocks). This objective was coupled with a spray program review (funded through USDA-SCRI "FRAME") and provided additional on sprayer calibration and coverage.

Objective 2 - *Survey newly established Washington vineyards to collect baseline data on the status of crown gall outbreaks as it relates to the source of vineyard planting materials* (FY18,19). This project, through surveying infected vineyards in Washington, gathered incidence data that will help determine on the field scale how effective the clean plant process is at reducing the severity of crown gall outbreaks in commercial vineyards.

This objective was a simple survey, designed to document crown gall incidence and severity in young vineyards from different source materials. The survey attempted to focus on vineyards planted with stock from the following sources: 1) WSDA Certified Nursery Stock originating from the Clean Plant Center Foundation Block; 2) WSDA Certified Nursery Stock originating from Foundation Plant Services Foundation Blocks; 3) Out-of-State Certified Nursery Stock (CA and OR certified, with known Foundation source); and 4) Non-certified vineyard stock. Emails and announcements were sent out to growers to self-identify if they have had a crown gall outbreak in the last 2 to 3 years. Additionally, growers who had recently contacted the PI regarding crown gall were also asked to participate. As a result of this "self-identified cooperation", we decided to scout vineyards that were up to 15 years old. The actual status of the planting material was confirmed by the source nursery.

The survey itself consisted of an in-person interview that included questions on: vineyard age, material source, variety (clone or selection number if known), irrigation practices, grow tube use and type, previous planting history of the site, and when the first outbreak occurred was collected. The survey was then completed with on-site scouting to determine the number of symptomatic vines in a given area, either through partial scouting of large blocks or scouting of full blocks if the total number of vines in the area were less than 400. For this, the number of healthy vines, galled vines, and missing or retrained vines were recorded, along with visible site characteristics (low spots, presence of wind machines, etc). The survey process and questionnaire were reviewed by WSU Institutional Review Board (IRB #16170-001) and deemed exempt from further review for participant protection.

Summary of Major Research Accomplishments and Results by Objective:

Objective 1 - *Monitor and map the incidence of fungicide resistance in powdery mildew populations in commercial vineyard settings*. The major success of our initial work in 2017, is that it allowed us to gather enough data to proceed with requesting, and winning, a federal USDA-SCRI project. Sub-objective specific results and accomplishments are described below.

Accomplishments. The combined results of these three subobjectives tells us that resistance to FRAC 11 fungicides is distributed across Washington. We also learned that the strategies we may need to take to help return to predominately sensitive powdery mildew populations are not going to be easy. We will likely have to take a state-wide, multi-crop approach to fungicide restrictions and rotations to reduce regional selection pressure for FRAC 11 fungicide resistance. This project has also suggested that resistance to other common fungicides, ones that will likely become more heavily relied on as individuals take a break from FRAC 11 fungicides, will become a potential challenge.

Results.

Objective 1a - Initial sampling and mapping. In 2017, growers submitted 247 total samples, using the tough-dot method (**Figure 3**). This particular year was a challenging year for mildew, and many of the samples came from sites experiences control program failures. Of those samples submitted, 89% of the samples were from mildew carrying the resistance gene. The remaining 11% was either a mixed population (i.e., where the sample contained mildew isolates with most the wild-type and the resistance gene, a common occurrence if a sample was taken from a severely infected leaf) or were from isolates that did not have the resistance gene.

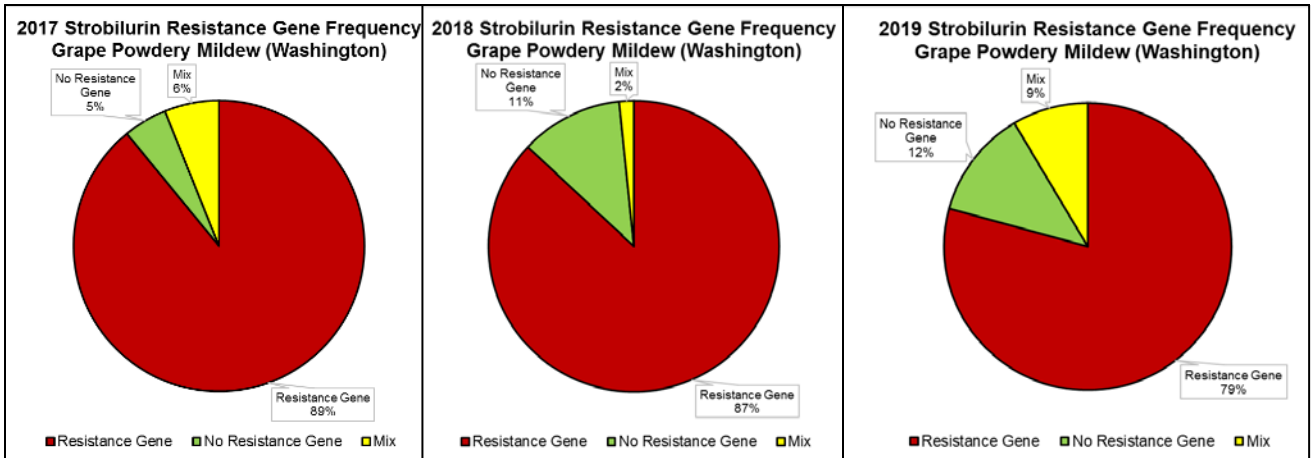


Figure 3 – Percent of grower-submitted samples in 2017, 2018, and 2019 that tested positive for the G143A resistance gene that typically confers resistance to FRAC 11 (QoI; strobilurin) fungicides.

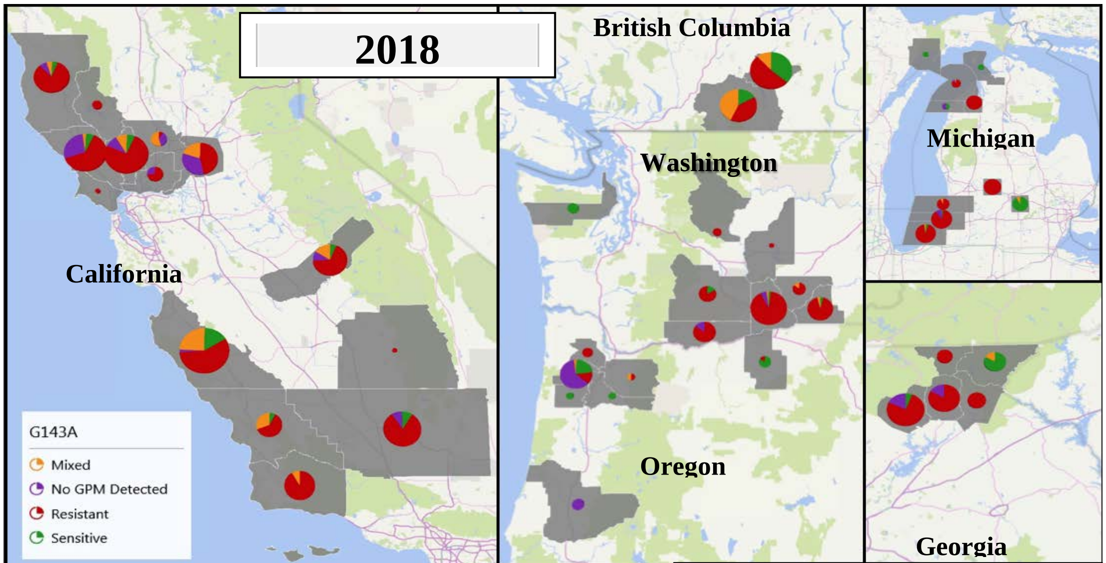
We received fewer grower-submitted samples in 2018 (n=129) and 2019 (n=82), but those sample numbers were compensated by increased scouting by our team (see Objective 1c). In these years, we also saw growers adopt the use of tank-mixing, tighter intervals, and reduction in FRAC 11 fungicide use. As a result, there were overall fewer control failures. Interestingly, from 2017 to 2019, we saw a slow, but steady, decrease in the percent of samples coming back with a positive detect of the resistance gene. We did see a growing number of mixed and no resistance gene populations, suggesting that perhaps we are starting to see a slow recovery of the population (i.e., return to wild type) with the altered regional use patterns of FRAC 11 fungicides, and stricter adherence to resistance management best practices. This population shift may also be a better reflection of the *actual* population makeup, as newer sampling strategies have reduced bias (i.e., are random, and include vineyards without control failures).

In all cases, powdery mildew samples were collected from almost every American Viticulture Area in the state – there is no single location that is exempt from potential FRAC 11 fungicide use. However, we did notice fewer positive detections for the resistance gene when samples came from regions were a significant proportion of the acreage in that area was farmed organically or farmed without nearby vineyards or orchards (which would also potentially use FRAC 11 fungicides). However, overall sample size from these locations was very limited. In addition, we did detect the resistance mutation in several samples in unsprayed Concord blocks – in these cases, the blocks were often next to nearby orchards, or by other specialty cropping systems (e.g., potatoes), where fungicides are often applied through irrigation (overhead), and the sites are prone to high wind. These types of occurrences suggest that the potential management of fungicide resistance will need to focus on regional, multi-crop systems, and will likely highlight the high-level of local potential drift that can occur in these different systems.

Objective 1b - Testing alternative mildew sampling methods. For this objective, we quickly moved from the use of Toughdot samples in 2017, to the almost exclusive use of the glove and swab methods for 2018 and 2019. While many growers still directly swab the mildew colonies, a few are starting to adopt the glove-and-swab technique. The primary reason for the switch from the Toughdot sampling techniques is that the use of the Toughdots was not particularly easy – it required skilled use of forceps, and many scouters complained of the dots (little stickers) getting lost or blown away when trying to remove their backing for use.

The direct-swabbing technique is an immediate replacement for the Toughdot procedure, in that it requires the scout to directly rub the swab on an existing mildew colony. But the catch to the process for both Toughdots and direct-swabbing is that existing mildew needs to be readily seen, which is not something someone wants to see in their vineyard. The adoption of the glove swabbing technique circumvents this issue by allowing a scout to sample before the colonies can be seen and in a much larger area (i.e., multiple rows or vines) and thus potentially increasing their sampling efficiency. However, it can also result in non-detects of mildew in the case where the technique is used in a vineyard where control is good and very little to no mildew is present.

Figure 4 (next page), from Dr. Walt Mahaffee's lab (USDA-ARS Corvallis), demonstrates the wide-spread use of this new swab technique across the country, and its ability to detect potentially resistant mildew. In 2018, the FRAME team processed 1400+ samples this way, and in 2019 (as of September), the team processed an additional 700+ samples this way. From 2019 on, all research and grower-submitted samples will be done using this rapid swabbing technique.



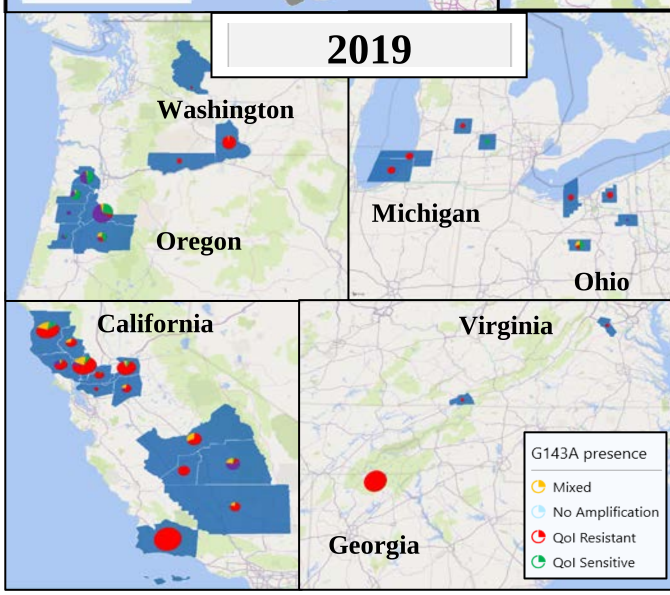


Figure 4 – Starting in 2018, the FRAME team adopted a nation-wide use of the cotton swab technique to sample for grape powdery mildew to determine the presence of the G143A mutation that confers resistance to FRAC 11 fungicides. This technique was able to adequate detect both powdery mildew and the resistance mutation and was easy to use and teach how to use. Note, a high-level of "no detects" was common when this technique was used to swab gloves early in the growing season – an indication of the low-levels of mildew present at the time of sampling.

Objective 1c - Measuring impact of mitigation strategies on fungicide resistant in powdery mildew populations. Much of 2018 was spent evaluating and interpreting fungicide resistance results from 2017 and finding potential growers and sites who would be willing to practice a couple of different spray regimes across their blocks. Unfortunately, we had limited interest in our most-affected growers on continuing to use a FRAC 11 fungicide (on a limited basis), so we spent that time re-designing this experiment, to begin to execute in 2019. In 2019, we did repeated time-sampling at several different grower blocks, both to determine when powdery mildew was showing up in the vineyard, and whether or not we were detecting the resistance mutation. In all cases, no FRAC 11 fungicides were immediately used in these blocks (as confirmed by submitted spray records), however, we were still able to detect the resistance mutation (**Figure 5; next page**). Using the glove method, we had several no-mildew detects early season (May to June), and fewer no-detections late season (July to harvest). The glove method is faster than directly-scouting for mildew colonies but having "no-detects" is a side-effect of that sped-up sampling process. In the early season, much of the actual mildew sampled was wild-type (susceptible to FRAC 11 fungicides), but we were able to pick up a few mixed and resistant individuals, *even though these sites were using early-season contact products, and not using FRAC 11 fungicides*. In the late season sampling, we see the proportions of wild-type and resistant individuals switch, with the majority being resistant. *Again, these were in sites that were not directly using FRAC 11 fungicides!* These results were both concerning and perplexing. Even more so, as this same population shift was seen in samples from all other FRAME-participating states. How is it that we get an increase in resistant individuals, when the selection event (i.e., using a FRAC 11 fungicide) is not occurring?

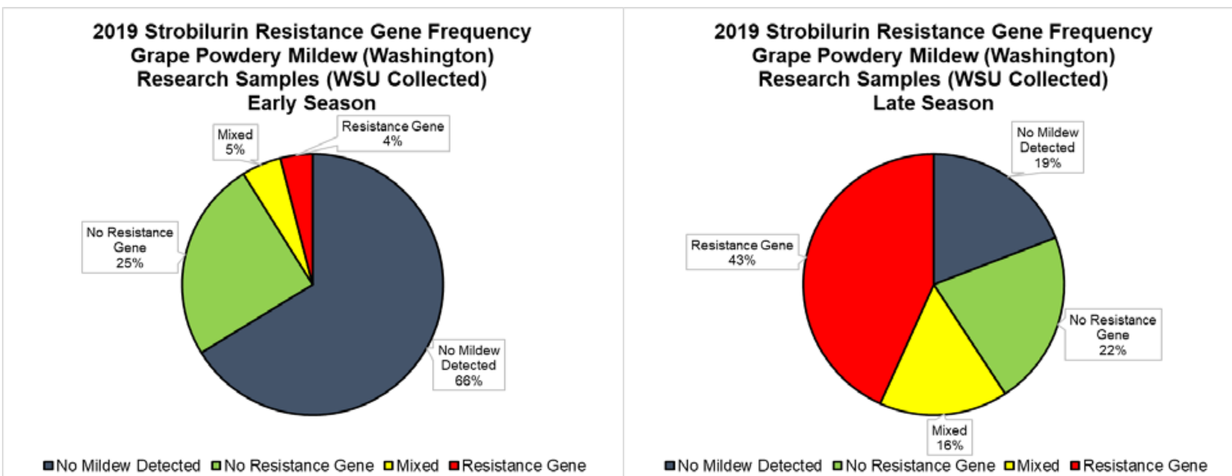


Figure 5 – In 2019, our WSU-directed research sampling using the glove method found low levels of mildew early in the growing season, much of which was sensitive to FRAC 11 fungicides. As we continued to scout, we still had sites with below-detection levels of powdery mildew (a sign of a good control program), but we did see increasing levels of mildew, and most of that mildew was resistant for FRAC 11 fungicides. In all cases, these were sites that were not actively using FRAC 11 fungicides in this growing season.

Through this process, we've also been collecting live mildew samples for laboratory evaluations of fungicide resistance. Initially, this was done to ensure our rapid genetic tests were able to accurately identify resistance phenotype. But also in this process, the FRAME team began to evaluate phenotypes to other classes of fungicides. We noticed that many samples coming in were resistant to both FRAC 11 (QoI) and FRAC 3 (DMI) fungicides. While many growers stopped using FRAC 11 fungicides in 2018 and 2019, they did continue to use FRAC 3 fungicides. If a grower happens to have a powdery mildew population where individual isolates are resistant to both FRAC 11 and 3, and continue to use FRAC 3 fungicides, we hypothesize that would result in the maintenance of the FRAC 11 resistance gene in the population. This is different than having a mixed population where some individuals are resistant to FRAC 3 fungicides, and others are resistant to FRAC 11 fungicides. Unlike FRAC 11 fungicide resistance, which is all-or-nothing, resistance to FRAC 3 fungicides is quantitative and different FRAC 3 active ingredients have different levels of efficacy, even in the face of resistant pathogens. Thus, having a FRAC 3 resistant isolate doesn't always mean that FRAC 3 products will stop working altogether, or at least, noticeably stop working right away. Many vineyards are still using these products with continued efficacy in their vineyards, despite some levels of resistance. Unfortunately, this will also continue to maintain the FRAC 11 resistant population at that site, prolonging the period before FRAC 11 fungicides can be efficaciously re-introduced into that site's spray regime.

Objective 2 - *Survey newly established Washington vineyards to collect baseline data on the status of crown gall outbreaks as it relates to the source of vineyard planting materials* (Years 1-2).

Accomplishments. With increasing variability in winter weather conditions, we have had multiple opportunities to identify and scout vineyards as it relates to crown gall outbreaks. This survey and scouting process became very educational, but not from the classic data collection standpoint. Fundamentally, it demonstrated that many growers across the state **do not understand what it means for vines to be "certified."** For most of our surveyed sites, people assumed all plant materials from certain nurseries were certified; in other words, they thought the nurseries were the certification unit, not the plant material. In some cases, they were also filling out orders that were short with non-certified planting material and intermixing those with certified material during the planting process. Through this survey, not only did we determine that there is an apparent association between nursery and foundation source, and subsequent risk for increase in crown gall severity, but we also learned that statewide efforts for "clean plant" education may have missed the mark or is not reaching its intended audience.

Results. Over two growing seasons (2017-2018), we have surveyed 58 different vineyard blocks across Washington state. These blocks vary in age (1-15 years old) and size. **Figure 6 (next page)** shows the average percent of vines displaying crown gall symptoms in a block, relative to their certification status. Excluding the CDFA certified (low number), and non-confirmed, using an unequal variance test indicated that there was a higher mean incidence of grown gall in non-certified vineyards, than those planted with WSDA and mixed-status vines (Kruskal-Wallis, $p=0.07$). We chose to not use the standard p=0.05 as our cut-off point, given the fact that the mixed category is highly variable, and difficult to ascertain the true proportion of certification status it contained. For most of the mixed-planting sites, most of the vines were certified, and the orders were simply "filled out" to their final number using non-certified materials. However, we could not trace planting material received to actual planting location in the block, so in mixed planting situations, the sub-sections scouted could be planted entirely to certified material, to a mix of certified and non-certified material, or entirely to non-certified material. These results highlight that while the clean plant process does not eliminate crown gall entirely (as also seen in recent reports by Yepes *et al.* 2019), it does help reduce the severity of an outbreak should one occur.

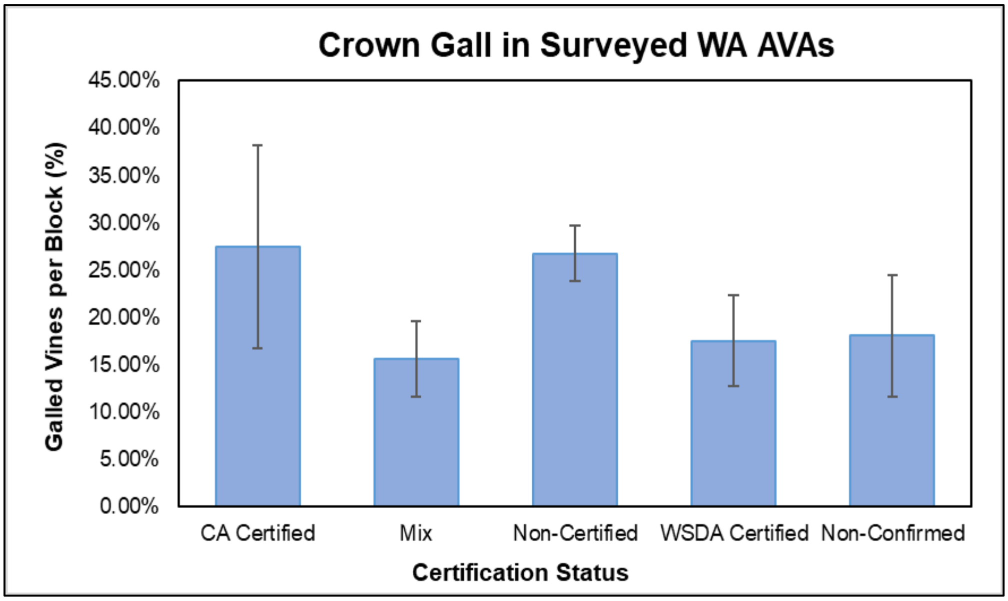


Figure 6 - Average crown gall symptom incidence in vineyards based on material source certification status.

Interestingly, it has been difficult finding sites planted with certified vines that have had noticeable / severe crown gall outbreaks. **Table 1** shows how the growers self-described the certification of their blocks (prior to or at the time of scouting) versus the *actual* certification of those blocks (confirmed post-scouting). It became increasingly clear in this survey that most growers think a nursery is certified, and do not always pay attention to the status of the actual vines they are ordering.

Table 1 – Grower described versus actual certification status of surveyed vineyards scouted in 2017 and 2018.

Certification Status	Grower-identified Certification Status (# of blocks)	Nursery-confirmed Certification Status (# of blocks)
CDFA Certified	2	2
WSDA Certified	27	9
Mix	3	7
Non-Certified	17	33
Non-Confirmed *	9	7
Total Blocks Scouted	**58**	**58**
*(Assumed certified, but waiting on confirmation from nursery)	**% assuming certified vines: 50%**	**% actually certified vines: 19%**

The general lack of awareness, or record keeping, of the source and certification status of planting material in many of Washington's newer (less than 15 years old) vineyards is concerning. The drive for rapid planting between 2005 and 2015 resulted in many growers forced to make the choice of planting right (certified vines) or planting quickly. This highlights the need for additional education and clarification on what plant certification means. It also highlights that many people, who may have filed complaints regarding the cleanliness (in terms of crown gall outbreaks) of their stock, could have been doing so in response to outbreaks in non-certified materials. This was a common mistake across small and large growers, and new and experienced growers alike.

Outreach and Education Efforts - Presentations of Research:

As with all our past projects, we have an extensive network of venues and opportunities we continuously engage in order to ensure information is readily accessible to the two stakeholder groups we serve: the scientific community and the industry. We do this through multiple venues including field days, grower meetings, extension publications, and peer-reviewed publications. A list of our communication efforts for this project is below.

Scientific Journals:

- Moyer, M.M., J. Newhouse, and M. Mireles. "Crown Gall Severity and "Certified" Status: A Washington State Survey". Catalyst. *In preparation.*

Presentations and Abstracts:

- "Fungicide Resistance and the Acronyms." 24 Jun 2020. Penn State Wine and Grape Team Webinar Series. ZOOM webinar.
- "Grape Disease Management – Powdery Mildew & Botrytis Bunch Rot." 9 Jun 2020. Wine Island Growers Association. ZOOM Webinar. (35 attendees).
- "What Makes for a Challenging Powdery Mildew Season? Environmental and Cultural Factors." 10 Mar 2020. FRAME Fungicide Resistance Management Workshop. Napa, CA USA.
- "Powdery Mildew: FRAMing the Reality of Fungicide Resistance." 28 Feb 2020. Business.Enology.Viticulture New York Annual Meeting. Rochester, NY USA.
- "Powdery Mildew Biology and Management." 21Feb 2020. FRAME Fungicide Resistance Management Workshop. Prosser, WA USA.
- "The Past, Present, and Future of Grape Pest Management." 17 Feb 2020. Ohio Grape and Wine Conference. Dublin, OH USA.
- "Powdery Mildew Biology and Management." 16 Feb 2020. Fungicide Resistance Management – A FRAME Workshop . Dublin, OH USA

- “The Bright Future of Powdery Mildew Management.” 6 Feb 2020. Unified Wine and Grape Symposium. Sacramento, CA USA.
- “Powdery Mildew Management Tactics in the Face of Fungicide Resistance.” 11 Nov 2019. Sustainable Ag Expo 2019. San Luis Obispo, CA, USA.
- “Managing Mildew and Fungicide Resistance: Back to Basics.” 1 Apr 2019. Colorado Grape Growers. Webinar.
- “Managing Crown Gall and Powdery Mildew Diseases in the Columbia Gorge.” 6 Mar 2019. Washington Advancements in Viticulture and Enology -Extension (WAVEx). The Dalles, OR USA.
- “Designing a Fungicide Program for Powdery Mildew.” 27 Feb 2019. FRAME Fungicide Resistance Management Workshop. Prosser, WA USA.
- “Managing Mildew and Fungicide Resistance: Back to Basics.” 21 Feb 2019. EJ Gallo Winery Annual Grower Meeting – North Valley. Lodi, CA USA.
- “Managing Mildew and Fungicide Resistance: Back to Basics.” 19 Feb 2019. EJ Gallo Winery Annual Grower Meeting – South Valley. Selma, CA USA.
- “Fungicide Management.” 14 Feb 2019. Washington Winegrowers 2019 Annual Meeting. Kennewick, WA USA.
- “L.I.V.E. Allowed Products and Fungicide Resistance Management.” 22 Jan 2019. Low Input Viticulture and Enology Certification Program Technical Group Meeting. Portland, OR, USA - Conference Call-In.
- “Grapevine Crown Gall and Powdery Mildew Update.” 15 Nov 2018. Washington State Grape Society Annually Meeting. Grandview, WA USA.
- Part 2: Influence of Weather on Mildew Spraying.” 5 Jun 2018. Ste Michelle Wine Estates Annual Grower Meeting. Prosser, WA USA.
- “Clean and Certified Vines: Where you can get them, and why source matters.” 1 May 2018. Regionalizing Grape Quarantines and Certification Programs in the Pacific Northwest. Yakima, WA USA.
- “Mildew, Mealybugs, Nematodes and Leaffolders – Local Monitoring for 2018.” 11 Apr 2018. Red Mountain Grower Group. Benton City, WA USA.
- “Managing Powdery Mildew in Difficult Years.” 30 Mar 2018. Washington Advancements in Viticulture and Enology -Extension (WAVEx) – Chelan. Tsillan Cellars, Chelan, WA USA**.**
- “Grape Powdery Mildew: Biology.” 21 Feb 2018. Oregon Wine Symposium. Portland, OR USA.
- “Grape Mildew Management: More than ‘What’s in the Tank.’” 15 February 2018. Sonoma County Grape Tech Group. Santa Rosa, CA USA.
- “Grape Mildew Management: More than ‘What’s in the Tank.’” 14 February 2018. Napa County Grape Tech Group. Napa, CA USA.

- "Season Game Changer: Powdery Mildew Fungicide Resistance." 25 Jan 2018. Oregon Vineyard Supply Pasco Grower Meeting. Prosser, WA USA.
- "Crown Gall & Winter Damage: Cold is a Relative Term." 23 January 2018. Oregon Vineyard Supply Grower Meeting. Salem, OR USA.
- "Grape Powdery Mildew: Management and Resistance." 17 Jan 2018. GS Long Grower Meeting. Yakima, WA USA.
- "Grape Powdery Mildew: Management and Resistance." 17 Nov 2017. Washington State Grape Society. Grandview, WA, USA.
- "Scouting Techniques for Vineyard Pest and Disease Management." 10 Aug 2017. Washington State Viticulture Field Day. Paterson, WA, USA.
- "Dual-Purpose Spray Program Design: Managing Mildew and Resistance." 29 Jun 2017. American Society for Enology and Viticulture Annual Meeting, Outreach Symposium. Bellevue, WA, USA.

Posters and Abstracts:

- Lowder, S., T. Neill, M.M. Moyer, T.D. Miles, and W. Mahaffee. 2019. Rapid Sampling Techniques to Monitor Quinone Outside Inhibitor Fungicide resistant *Erysiphe necator*. (abstr.-poster). Phytopathology. 109:S2.81. https://doi.org/10.1094/PHYTO-109-10-S2.1
- Lowder, S., T. Neill, M.M. Moyer, T Miles, and W. Mahaffee. 2018. Rapid Sampling Techniques to Determine QoI Fungicide Resistance in *Erysiphe necator*. (abstr. – poster). International Congress for Plant Pathology. Boston, MA, USA. Phytopathology 108:S1.1. https://doi.org/10.1094/PHYTO-108-10-S1.1
- Moyer, M.M., and W.F. Mahaffee (eds). 2017. Proceedings of the 8th International Workshop on Grapevine Downy and Powdery Mildew. Jul 17-19, 2017. Corvallis, OR, USA. [Online]: http://extension.wsu.edu/conferences/8th-international-workshop-grapevine-downy-powdery-mildew/

Extension Publications:

- Fall 2018 VEEN Article: "Detecting DMI fungicide resistance in grape powdery mildew." See: http://wine.wsu.edu/extension/viticulture-enology-news-veen/
- Hoheisel, G.A., and M.M. Moyer (eds). Updated Annually. Pest Management Guide for Grapes in Washington. WSU Extension #EB0762. Pullman, WA, USA. 68 pp. (Zasada is the author of the nematode section).

Other Media:

- Moyer, M. M. Cooper, P. Brannen, W. Mahaffee, M. Lewis-Ivey, T. Miles and C. Oliver. 2019. *Good to Know: Why Some Seasons are Worse for Powdery Mildew*. Good Fruit Grower. Nov 2019: 50-53. Online.
- Hansen, M., and M. Moyer. 2019. *Basic Training for Combating Mildew*. Wine Business Monthly. March 2019: 84 – 91. Online: https://www.winebusiness.com/wbm/
- "WAVE Minute: Latest on Powdery Mildew Research". 9 May 2019. Washington Ag Network Radio Show and Webcast. Developed in partnership with the Washington State Grape and Wine Research Program.
- "WAVE Minute: Continuing Powdery Mildew Research." 5 Apr 2018. Washington Ag Network Radio Show and Webcast. Developed in partnership with the Washington State Grape and Wine Research Program.
- "Wave Minute: Powdery Mildew Update." 29 Mar 2018. Washington Ag Network Radio Show and Webcast. Developed in partnership with the Washington State Grape and Wine Research Program.

Workshops / Working Groups:

- *We have hosted multiple full-day workshops related to FRAME, which are not listed here. Two such workshops were in WA, and several others across the country.*
- Hansen, M., and **Moyer M.M.** 30 Mar 2018. "WAVEx Chelan." Washington Advancements in Viticulture and Enology -eXtension Workshop Series. Tsillan Cellars, Chelan, WA USA**.** (25 Participants; 3,259 Acres represented)
- Hansen, M. and **M.M. Moyer.** 6 Mar 2019. WAVEx. The Dalles, OR, USA. (21 participants, 7,374 acres represented, 2 WSDA and ODA Pesticide). *This workshop is in partnership with the Washington State Wine Commission.*
- Mahaffee, W., and **Moyer, M.M**. 13-14 Dec 2017. Fungicide Resistance Assessment, Mitigation, and Extension Network Working Group. Napa County Extension Office. Napa, CA, USA.
- Mahaffee, W. and **M.M. Moyer.** 17-20 Jul 2017. "8th International Workshop on Grapevine Downy and Powdery Mildew". Corvallis, OR, USA

Research Success Statements:

This project has directly led to an industry shift if fungicide use. With the wide-spread knowledge of the control challenges potentially associated with FRAC 11 fungicides, these products are now being used with caution. From our discussions with growers (and through observation and review of submitted spray programs), many have either reduced FRAC 11 fungicide use down to 1 a growing season (tank mixed with another MOA) or have eliminated it from their annual regime (either "for the time being", or on a yearly rotation). More growers have also requested additional tests for other FRAC groups (not currently available yet) to better inform their product selections. We have also noticed a shift away from stretched fungicide intervals (17+ days), which reflects an acceptance and understanding of our fungicide resistance mitigation "best practices" extension efforts. This project has also highlighted that additional education is needed as to what the value of certified plant material is, and how to properly use certified planting material (i.e., all vines must be certified) in order to realize those benefits. The use of certified vines significantly reduced the mean severity of crown gall expression in blocks compared to those planting without certified vines. For those expanding vineyard plantings into potentially cold sites, the use of certified vines will be important to prevent vineyard loss due to crown gall, especially during establishment years. While this study focused on the expression of crown gall after cold events, these same concepts can be applied to those vineyard situations preparing for grafting-over, which also induces wounds that can trigger gall expression at the grafting site.

Funds Status:

A no-cost extension of the budget has been requested (until June 2021), given that fund expenditure rate was slower than expected. This was due to acquisition of other funds that supported technicians originally assigned to this project (USDA-SCRI-CAP project); and the original funding of the project using state (10A) funds that cover project personnel benefits. The additional no-cost extension is being used to continue to support fungicide resistance monitoring and purchasing of additional supplies for fungicide swab kits and workshop delivery / grower training.

Literature Cited:

Falacy JS, Grove GG, Mahaffee WF, Galloway H, Glawe DA, Larsen RC and Vandermark GJ. 2007. Detection of *Erysiphe necator* in air samples using the polymerase chain reaction and species-specific primers. Phytopathology 97:1290-1297. DOI: 10.1094/PHYTO-97-10-1290

Miles TD, Neill TM., Cole M, Warneke B, Robinson G, Sterigiopoulus I, and Mahaffee WF. 2020. Allele-specific detection methods for QoI fungicide resistant *Erysiphe necator* in vineyards. Plant Disease. *Accepted – in final revision.*

Yepes LM, Burr T, Reid C, and Fuchs M. 2019. Elimination of the Crown Gall Pathogen, *Agrobacterium vitis,* from Systemically Infected Grapevines by Tissue Culture. Am. J. Enol. Vitic. 70: 243-280. DOI: 10.5344/ajev.2019.18083