Managing Grapevine Powdery Mildew with Ultraviolet-C Light in Washington State

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Abstract:

Context and purpose of the study – Germicidal ultraviolet-C (UV-C) light has shown promising results for suppression of several plant-pathogenic microorganims, including *Erysiphe necator*, which attacks grapevine. In Washington State the majority of winegrape production is in a semi-arid steppe environment, with historically low powdery mildew disease pressure, making it a promising area to deploy UV-C as a disease management tool. Trials focusing on UVC application timing and frequency will assist in developing regionally-appropriate application recommendations for eastern Washington State.

Material and methods – Trials were repeated for three years in a *Vitis vinifera* 'Chardonnay' vineyard at Washington State University (2020, 2021, and 2022) in Prosser, WA, USA. We evaluated the use of UV-C (200 J/m^2) in a vineyard setting under different application regimes focused on timing (season-long, or early-season only), and frequency (intervals of application). In 2020, UV-C was applied weekly; in 2021 and 2022, UV-C was applied weekly or twice-weekly. Early-season applications were made between 15 cm shoot growth to prebloom. After prebloom, early-season vines switched to a standard fungicide spray program. In season-long trials, treatments were applied through 4-weeks postbloom. Control treatments included season-long unsprayed and a season-long fungicide program. In the early-season trials, a third control was included: unsprayed until prebloom, then sprayed after prebloom. Powdery mildew disease severity was visually rated on leaves and clusters bi-weekly from bloom until harvest.

Results – For early-season treatments, weekly UV-C in 2020 reduced foliar disease by 85% relative to the season-long unsprayed (p=0.003). In 2021, there was virtually no disease (extended "heat dome" events from bloom through véraison), and treatment separation. In 2022, compared to the season-long unsprayed, weekly or twice-weekly early-season UV-C reduced foliar disease by 77% (p=0.0001) and 74% (p=0.0001); cluster disease was reduced by 78% (p=0.0001) and 74% (p=0.0001). For season-long treatments, UV-C in 2020 and 2021 did not significantly reduce foliar disease relative to the season-long unsprayed, though there was a trend for increasing control with more frequent UV-C intervals. For example, foliar disease was 25% and 50% less in 2020 and 2021 (respectively) with weekly UV-C; foliar disease was 79% less in 2021 for twice-weekly UV-C. In 2022, season-long weekly UV-C reduced foliar disease severity by 37% (p=0.03) and twice-weekly UV-C reduced foliar disease by 61% (p=0.0003) relative to the season-long unsprayed control. Cluster disease severity was reduced in 2022 by 40% (p=0.0001) with season-long twice-weekly UV-C and 16% (p=0.03) with season-long weekly UV-C compared to the season-long unsprayed control. While not always statistically significant, the consistent trend in reduction of powdery mildew disease severity by using UV-C weekly or twice-weekly, suggests that UV-C could be an additional tool for alternative powdery mildew management in eastern Washington winegrape vineyards.

Keywords: Grapevine, *Erysiphe necator*, Grapevine Powdery Mildew, Pest Management, Ultraviolet-C Light.

1. Introduction

Germicidal ultraviolet-C (UV-C) is comprised of highly energic wavelengths between 200 to 280 nm. UV-C has been shown to effectively suppress powdery mildews on several crops, including *Erysiphe necator* on grapevine (Gadoury et al., 2022; Ledermann et al., 2021). UV-C has been used for nearly 80 years in hospitals and microbiology research to limits harmful microbes, but it's effective use against plant pathogens is relatively recent. A better understanding of how UV-C suppresses plant pathogens, and how pathogens repair that damage, has led to an improvement efficacy of UV-C treatments by applying UV-C during a dark period that extends at least 4 hrs after application (Janisiewicz et al., 2016; Suthaparan et al., 2016; Onofre et al., 2019). Microbial pathogens, such as powdery mildews, possess a robust photolyase repair mechanism that repairs UV-inflicted damage to a pathogen's DNA. This repair mechanism is driven by the blue and UV-A component of sunlight (Beggs, 2002). Therefore, the repair mechanism cannot operate during darkness, and failure to repair the damaged DNA is invariably lethal to microbial pathogens if they receive a sufficient UV dose. The dose required to kill a single-celled microorganism is usually at least one order of magnitude below a level that harms plants, so the UV dose that kills *Erysiphe necator* is harmless to a grapevine (Gadoury et al., 2022).

In Washington state (USA), the majority of winegrape (*Vitis vinifera*) production is in a semi-arid steppe environment, averaging 1,600 growing degree days (1 Apr to 31 Oct, base 10°C), in-season (Apr to Oct) average daily maximum temperature ranging from 12 to 35°C, and average annual precipitation of 164 mm, with 76 mm falling between April and October ("Prosser NE" station; weather.wsu.edu, 10-yr averages from 2009 to 2019). These climate conditions results in low grape powdery mildew disease pressure, and winegrape vineyards use approximately 4 to 7 fungicide applications a season to control this disease (Hoheisel and Moyer, 2023). Fungicide applications typically occur between 8 to 16 cm shoot growth and 4 weeks postbloom; where the most effective chemistries are used during the critical window for berry infection, two weeks pre-bloom to 4 weeks postbloom (Gadoury et al., 2003; Moyer et al., 2016). After 4 weeks post bloom, low relative humidity and high maximum temperatures significantly reduce the favorability for disease development. With the region's lower powdery mildew disease pressure, the aim of this research was to determine if UV-C could be used as a chemical-free alternative for disease management in *V. vinifera* vineyards, and how to develop regionally-appropriate application recommendations for eastern Washington State.

2. Material and methods

Vineyard - Trials were repeated for three years in a *V. vinifera* 'Chardonnay' vineyard at Washington State University (2020, 2021, and 2022) in Prosser, WA, USA. The vineyard was planted in 2009 with 1.8 x 2.7 m (vine x row) spacing, and north-south row orientation. Vines were trellised on a modified vertical shoot positioning system and trained to a dual-trunk bilateral cordon with spur pruning. The vineyard was drip-irrigated with natural vegetation under vine and between the rows maintained through routine in-season mowing. Minimal canopy management was applied for all three years, with hedging occurring at BBCH 71 in 2020 and 2021, and shoot thinning occurring during BBCH 68 in 2022.

Experimental Design - We evaluated the use of UV-C (200 J/m^2) under different application regimes focused on timing (early-season only, or season-long), and frequency (intervals between applications). In 2020, UV-C intervals were applied weekly; in 2021 and 2022, UV-C intervals were applied weekly or twice-weekly. Early-season applications were made between BBCH 13 to BBCH 57 (approx. 15 cm shoot growth to rachis elongation). After BBCH 57, early-season UV-C treatments switched to a standard fungicide spray program that ended 4-weeks postbloom. In season-long trials, treatments were applied from BBCH 13 to approximately BBCH 73 (4 weeks postbloom). Control treatments included a season-long unsprayed regime and a season-long full fungicide program. In the early-season trials, a third control was included: early-season unsprayed, unsprayed until BBCH 57, then switched to the standard fungicide spray program until BBCH 73.

Disease severity ratings of *E. necator* were recorded starting 10 June 2020 (BBCH 69), 8 June 2021 (BBCH 71), and 14 June 2022 (BBCH 62) and continued until right before harvest at the end of August to early September. The upper and lower surfaces of 40 random leaves and 20 random clusters per treatment were rated in 2020. This was expanded to 40 clusters in 2021 and 2022. Ratings were done by trained raters, and occurred every 7 to 14 days during the rating period.

Statistical analysis - All statistical analyses were analyzed using JMP statistical program (v. 6.0.0, SAS Institute Inc., Cary, NC) with the standard least squares model platform. Foliar and cluster disease ratings were evaluated by calculating area under the disease progress curve (AUDPC) (Simko and Piepho, 2012). Treatments were analyzed with ANOVA and Tukey's HSD were used to determine significance (α = 0.05).

3. Results and discussion

For early-season only treatments, weekly UV-C reduced foliar disease by 85% and cluster disease severity by 86% relative to the season-long unsprayed vines in 2020 (p=0.003 and 0.06, respectively). In 2020, all early season treatments that were switched to the fungicide program at BBCH 57 (early-season unsprayed, fungicide program, and weekly UV-C) were not significantly different. In 2021, due to an extended "heat dome" event from bloom through véraison (temperatures exceeded daytime highs of 35°C for 17 consecutive days), there was little to no natural foliar or cluster disease in the vineyard, resulting in the inability to separate treatment means.
The 2022 vintage was a higher-pressure disease year, with below average temperatures and above average precipitation early in the season. Compared to the season-long unsprayed vines, use of UV-C weekly or twice-weekly early-season application of UV-C reduced foliar disease by 74-75% (p=0.0001 for both UV-C intervals); cluster disease was similarly reduced by 74%-78% (p=0.0001 for both UVC treatments). Similar to 2020, early-season 2022 UV-C treatments foliar and cluster disease severity were not significantly different than early-season unsprayed and the fungicide program. Combined, this emphasizes that the application of *any* program that seeks to maximize the suppression of grapevine powdery mildew on fruit requires extreme diligence during the critical window of berry susceptibility extending from immediate prebloom to 14 days postbloom (Gadoury et al 2003; Gadoury et al 2007; Ficke et al 2004; Gee et al., 2008). Berry infections that may not become macroscopically visible until much later in the season, indeed until harvest, can only be established during this relatively short period of time. Actions before and after this critical window are beneficial to canopy health, and early infection to some degree predetermines the inoculum load on foliage that threby endangers fruit. Failure to apply the most effective suppressive actions diligently during the critical window leads to failure in adequate disease suppression on fruit. This is true with respect to fungicide rates, frequency of application, innate efficacy of a compound, or presence of resistance to a compound. It is equally true with respect to the use of UV-C. Hence, UV-C could be best integrated into early season spray programs for growers who wish to reduce overall pesticide applications without assuming excessive risk of fruit infection and thereby compromising final fruit quality.

For season-long treatments, overall disease levels of UV-C treatments in 2020 and 2021 were low due to macroenvironment, indicated above, making treatment separation difficult. Though UV-C treatments were not statistically different from the unsprayed control, there was a trend of increased foliar disease control as UVC application tightened. Weekly UV-C applications reduced foliar disease severity compared to the season-long unsprayed control by 25% in 2020 and 50% in 2021, and twice-weekly applications of UV-C reduced foliar disease severity by 79% in 2021. However in 2020, weekly UVC foliar disease severity was higher then the fungicide program (p=0.02) and cluster disease was the same in all treatments (p=0.09). In 2021, all treatments were not significantly different from each other for foliar disease severity (p=0.09) and there was no cluster disease, due to heat events. In 2022, weekly UV-C applications reduced foliar disease severity by 37% (p=0.03; Fig. 1A), and twice-weekly UV-C reduced foliar disease by 61% (p=0.0003; Fig. 1A) relative to the season-long unsprayed control. Cluster disease severity was reduced by 16% with weekly UVC applications (p=0.03; Fig. 1B) and by 40% with twice-weekly UV-C applications (p=0.0001; Fig. 1B) compared to the season-long unsprayed control. Though UV-C was significantly lower then the season-long unsprayed, it was not as effective as the the fungicide program for controlling foliar or cluster disease. Compared to the fungicide program, weekly and twice-weekly UVC foliar disease was higher (p=0.0001 and p=0.01, respectively, Fig. 1A). Cluster disease for weekly and twice-weekly was higher compared to the fungicide program (p=0.0001 for both UV-C treatments, Fig. 1B). These results show that season-long UV-C treatments are effective at reducing overall disease, though for grower adoption this technology needs to be as efficacious as their current fungicide spray programs.

4. Conclusions

The use of UV-C, like other contact-type fungicides, will require careful consideration of pathogen biology and epidemiology, critical periods of host susceptibility to infection, as well as local climate conditions and vineyard management practices, in order to determine how to best integrated the technology with regional production systems. In the case of Washington State we typically have unfavorable macroclimate conditions for high disease pressure. The ultimate effect of such periods depends upon whether they fall outside or within the time of key epidemiological events. Likewise, vine microclimate conditions can impact both fungicide applications and UV-C applications. In this experiment our canopies were larger and more-spraling due to the minimal canopy management perform. This led to poor fungicide application penetration, seen in the fungicide program disease severity were cluster disease was at unacceptable levels, and potentially poor UV-C penetration. Early-season canopy density or canopies that are managed may be less restrictive to both fungicide and UV-C penetration. Nonetheless, there are important distinctions to be made between fungicides and UV-C in grapevine disease suppression. UV-C has no residual activity, and depends upon access to the target at the time of application. While this is also true with fungicides to a degree, fungicides also have residual activity and can redistribute in rainfall or in dew films, or systemically. Thus, canopy management, shoot thinning, and leaf removal, while important to fungicide penetration, may be even more important for efficacy of UV-C applications.

5. Acknowledgments

Funding for this project was provided through the Washington State Grape and Wine Research Program, including Washington State Wine Commission, Auction of Washington Wines, State Liter tax, and/or WSU Agriculture Research Center. This research was also partially funded by USDA National Institute of Food and Agriculture Hatch project 1016563.

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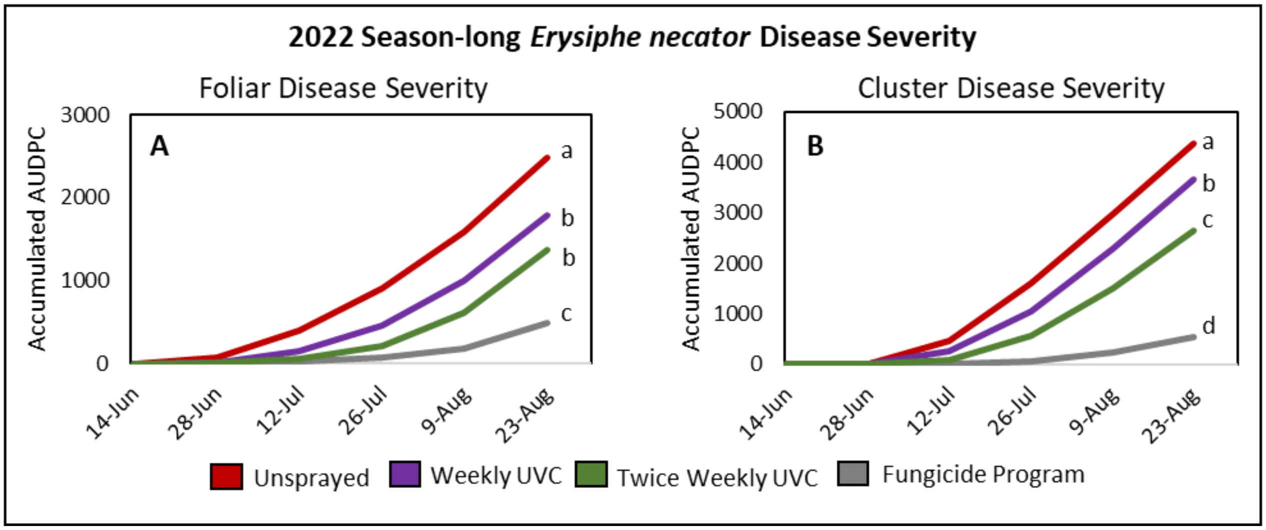

Figure 1: Foliar and cluster disease severity for 2022 season-long UVC trial represented by accumulated area under disease progress curve (AUDPC). Unsprayed: season-long unsprayed, Weekly UVC: season-long weekly UVC, Twice weekly UVC: season-long twice weekly UVC, and Fungicide Program: season-long fungicide program. **A)** Foliar disease on weekly UVC and twice weekly UVC treated vines was lower than the season-long unsprayed control, but were not as fully effective as a the full fungicide regime. **B)** Weekly UVC and twice weekly UVC resulted in lower cluster disease severity than the season-long unsprayed vines, but had higher disease severity than clusters receiving a season-long fungicide program.