Use of Germicidal UV Light to Suppress Grapevine Diseases and Arthropod Pests

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1 Introduction

Global winegrape production is based on production of *Vitis vinifera*, a host species comprised of cultivars that are highly susceptible to infection by *E. necator*, as well as several other fungal and oomycete pathogens. Fungicidal suppression of grapevine powdery mildew is especially problematic. Resistance to several fungicide classes is widespread. Many viticultural regions are within Mediterranean climates, with little rainfall during the crop production season. This creates an environment where powdery mildew predominates as a principal threat to healthy fruit and foliage. Availability of a non-fungicidal option for suppression of powdery mildew is therefore highly desired by the grape and wine industry. Nighttime applications of ultraviolet light in the UV-C bandwidth have shown a high degree of suppression of powdery mildews of several hosts. Our objectives were to (i) determine if nighttime UV-C applications can suppress grapevine powdery mildew; (ii) to determine if these UV-C application affect vine growth, yield, or crop quality; and (iii) determine if applications targeting powdery mildew suppress other pests or diseases of grapevine. Preliminary reports of this work have been published (Gadoury et al 1992, Gadoury 2019, Gadoury 2021).

2 Background and Justification

Powdery mildew pathogens are largely external to the host, and occupy a niche exposed to sunlight, including biocidal UV-B wavelengths between 280 and 290 nm (Suthaparan et al 2016). Although favored by shade and repressed to some degree by direct sunlight exposure (Austin and Wilcox 2011; Austin and Wilcox 2012; Willocquet *et al* 1996), powdery mildews persist due to their ability to repair UV-B-inflicted damage to their DNA through a photolyase mechanism driven by blue light and UV-A (Thompson and Sancar 2002; Suthaparan et al 2014). The requirement of sunlight for photolyase repair of DNA has been exploited by exposing plants to UV-B or UV-C during nighttime (Patel *et al* 2020; Janisiewicz *et al.* 2016a, 2016b; Suthaparan *et al.*, 2012; 2014; 2016; 2017). The UV spectrum used in such studies has ranged from a UV-B waveband between 280 to 290 nm, to near-monochromatic UV-C produced by low pressure discharge lamps yielding a peak output near 254 nm (Onofre et al 2021). Reduction of the severity of several powdery mildews has been attributed to direct damage to the pathogen by UV exposure (Austin and Wilcox 2012; Gadoury *et al* 1991, Onofre *et al* 2021, Suthparan *et al* 2012; 2014; 2016). UV-B and UV-C have been reported to be directly inhibitory to *Botrytis cinerea* on strawberry (Janisiewicz *et al.* 2016a) and geranium (Darras *et al.*, 2015), and phytophageous mites on strawberry (Osakabe 2021). In contrast, pathogens other than powdery mildews have been suppressed by exposure of their hosts to UV-C prior to inoculation (Buxton *et al.,* 1957; Kunz *et al.*, 2008; Patel *et al.*, 2017), possibly due to enhancement of host resistance, and Ledermann *et al* (2021) recently reported that preinfection exposure of grapevines to UV-C increased host resistance to infection by *E. necator*.

Practical nighttime treatments of vineyards with UV-C treatments has necessitated development of UV-C arrays powerful enough to apply effective doses at speeds that allow the equipment to complete treatments during the available night interval, often in late Spring and early Summer, during some of the shortest nights of the year. A tractor-drawn UV-C apparatus was designed and constructed in an earlier study (Onofre *et al* 2021) to suppress strawberry powdery mildew (*Podosphaera aphanis*). A long-term goal of our research is

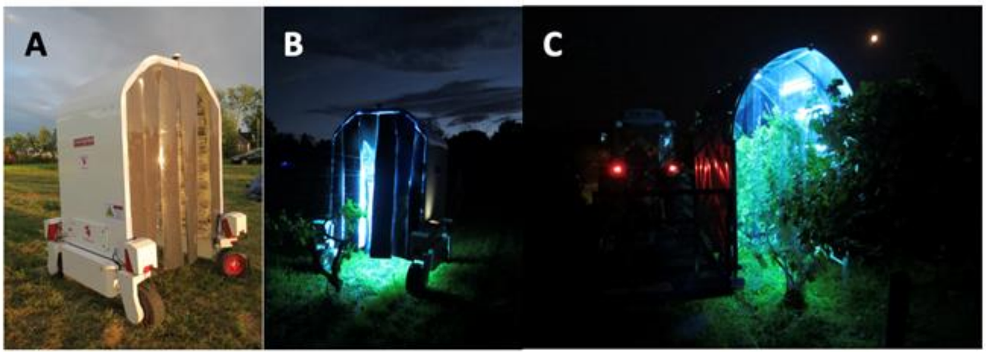

Figure 1: UV lamp arrays used for nighttime applications in vineyards were either carried by an autonomous robotic carriage (A and B), or were tractor-drawn (C)

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to develop light-based disease suppression technology for other crops. We chose grapevine and *Erysiphe necator* as the next pathosystem for investigation. Therefore, an array similar to that used in our strawberry research was configured for trellised grapevines for both a tractor-drawn carriage and a fully autonomous robotic carriage (**Fig. 1**) for vineyard applications. The arrays were used in research in Geneva New York, USA, as well as in commercial vineyards in Dresden NY, USA from 2019 to 2021. Although originally focused on suppression of powdery mildew, activity against downy mildew, the sour rot complex, and mites was also demonstrated.

3 Results of Laboratory and Field Studies

In laboratory studies, UV-C light (peak 254 nm, FWHM 5 nm) applied during darkness strongly inhibited the germination of conidia of *Erysphe necator*, and at a dose of 200 J/m^2 germination was nil. Reciprocity of irradiance and duration of exposure with respect to conidial germination was confirmed for UV-C doses between 0 and 200 J/m^2 applied at 4 or 400 seconds. When detached grapevine leaves were exposed during darkness to UV-C at 100 J/m^2 up to 7 days before inoculation with zoospores of *Plasmopara viticola,* infection and subsequent sporulation was reduced by over 70% compared to untreated control leaves, indicating an indirect suppression of the pathogen exerted through the host (**Fig. 2).**

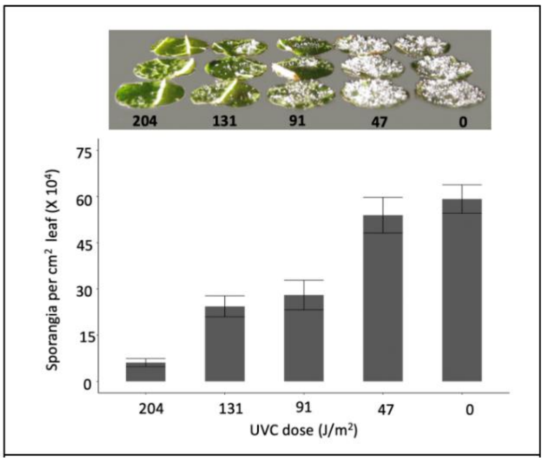

Figure 2: Effect of a single preinfection application of UV-C to *Vitis vinifera* 'Chardonnay'. Leaves were exposed to UV-C during darkness and were then inoculated with sporangia of *Plasmopora viticola* 12 hr later. Sporangia were harvested and enumerated 7 days later.

In 2019 and 2020 in a Chardonnay research vineyard containing approximately 10% unsprayed or minimally-sprayed vines and a history of severe disease, the severity of powdery mildew on fruit was significantly reduced compared to untreated controls, and twice-weekly applications at 200 J/m^2 provided suppression equivalent to a standard fungicide program (**Fig. 3**). Although weekly applications of UV-C at 100 and 200 J/m2 in combination with a minimal fungicide program provided adequate suppression of downy mildew in 2019, no UV-C treatments reduced the severity of *P. viticola* in 2020 when used as stand-alone treatments on Chardonnay. However, twice-weekly applications of UV-C did significantly suppressed severity of downy mildew on the *Vitis* interspecific hybrid cultivar Vignoles in 2021. It would appear that UV-C is insufficient as a control for downy mildew when used alone on the most susceptible grape cultivars, but could be a valuable part of an IPM program when combined with fungicides on susceptible cultivars, or when combined with host resistance on certain interspecific hybrid cultivars.

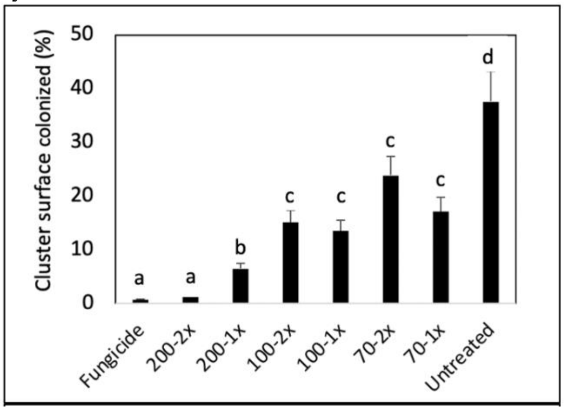

Figure 3: Severity of powdery mildew on Chardonnay fruit treated weekly (1X) or twice-weekly (2X) with UV-C at 70, 100, or 200 J/m2 compared to positive (Fungicide) and negative (Untreated) controls.

In commercial Chardonnay vineyards with histories of excellent disease control in Dresden, NY, *E. necator* remained at trace levels on foliage and was nil on fruit following weekly nighttime applications of UV-C at 200 J/m^2 in 2020, and after weekly or twice-weekly application of UV-C at 100 or 200 J/m^2 in 2021. UV-C would appear to be a very effective means to suppress powdery mildew, and indeed might allow grapes to be produced with minimal or no fungicides in regions where powdery mildew is the predominant threat.

In 2019 and 2021 weekly and twice weekly nighttime applications of UV-C at 200 J/m^2 also significantly reduced the severity of sour rot, a decay syndrome of complex etiology, on fruit of the *Vitis* interspecific hybrid cultivar 'Vignoles', but not the severity of bunch rot caused by *Botrytis cinerea*. (**Fig. 4**).

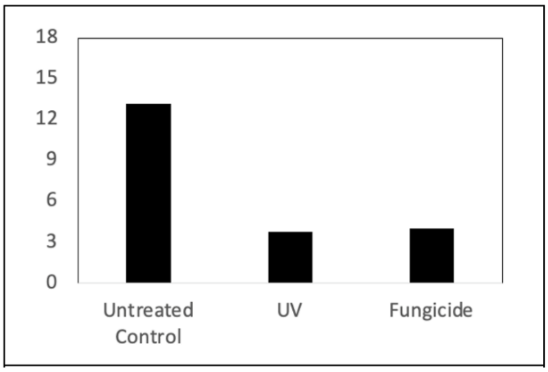

Figure 4: Severity of sour rot on Vignoles grapes either untreated, treated twice weekly with UV-C at 200 J/m2, or treated with fungicide.

Nighttime UV-C applications did not produce detectable indications of phytotoxicity, growth reduction, or reductions of fruit yield or quality parameters, even at the highest doses and most frequent intervals employed.

In laboratory studies, treatment of the egg stage of twospotted mites resulted in near complete egg mortality. Activity of UV-C doses was progressively less effective as juvenal mites matured. However, both immatures hatching as survivors from treated eggs, as well as surviving immature mites displayed reduced fecundity. Thus, even sublethal doses of UV-C may have a pronounced effect over time on population dynamics of phytophagous mites.

4 Conclusions

UV-C is a technology with significant, substantial, and reproducible efficacy against a broad spectrum of powdery mildew pathogens on many crops, to which the present study has added grapes. While the mode of action of UV-C appears to be mostly eradicative, there were secondary effects that increased resistance to *Plasmopara viticola*. While not universally effective against all pathogens, a surprising spectrum of efficacy has now been demonstrated in grapes and several other crops. In grapevine, UV-C applied at up to 200 J/m^2 twice weekly produced no deleterious effects on plant development, physiology, yield, or crop quality.

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