USE OF UV LIGHT FOR SUPPRESSION OF GRAPEVINE DISEASES

David M. GADOURY[1*], Lance CADLE-DAVIDSON[2], Kaitlin GOLD[1]

[1]*Plant Pathology and Plant-Microbe Biology Section, Cornell AgriTech, Geneva, NY 14456 USA*
[2]*USDA-ARS Grape Genetics Research Unit, Geneva, NY, 14456 USA*

*Corresponding author: David M. Gadoury (dmg4@cornell.edu)

Abstract:

Context and purpose of the study - Microbial pathogens of plant have evolved to sense, interpret, and use light to direct their development. One aspect of this evolved relationship is photolyase-mediated repair of UV-induced damage to pathogen DNA. Application of germicidal UV (UV-C) at night circumvents the blue light-driven repair of pathogen DNA and allows non-phytotoxic doses of UV-C to suppress a variety of pathogenic microbes and even certain arthropod pests without damage to vines or fruit. Lamps arrays have been designed specifically for the canopy architecture of grapevines and have been deployed on both tractor-drawn and robotic carriages for partial to near-complete suppression of powdery mildew (*Erysiphe necator*), sour rot (fungal, bacterial, and arthropod complex), and downy mildew (*Plasmopara viticola*).

Material and methods – Low-pressure discharge UV-C lamps (Osram HNS G13 55W UV-C, peak 253.7 nm, FWHM < 5nm) were used in both laboratory and vineyard studies over a 4-yr period in New York on *Vitis vinifera* 'Chardonnay' and the *Vitis* interspecific hybrid cultivar 'Vignoles'. Detached leaves inoculated with conidia of *E.necator* or sporangia of *P. viticola* were exposed during darkness to UV-C at 25 to 200 J/m^2. In addition to laboratory studies, Chardonnay and Vignoles grapevines were exposed to weekly or twice-weekly nighttime applications of UV-C at 70 to 200 J/m^2. For vineyard applications, the lamps were borne in a hemicylindrical array backed by polished aluminum reflectors. The front and back of the array was fitted with reflectorized curtains to provide additional reflectance angles and improved canopy penetration. Arrays were moved through the vineyards using either tractor-drawn or autonomous robotic carriages. Several physiological and physical responses of the grapevines were monitored on UV-treated and non-UV-treated vines.

Results – Twice-weekly nighttime applications of UV-C at 200 J/m^2 provided consistent suppression of powdery mildew in high-inoculum Chardonnay research vineyards. In lower inoculum commercial Chardonnay vineyards, 200 J/m^2 applied weekly at night was sufficient to suppress powdery mildew to trace levels. No rate or frequency of UV-C provided significant suppression of downy mildew on Chardonnay (highly susceptible), but twice-weekly nighttime applications of UV-V at 200 J/m^2 suppressed downy mildew on Vignoles (moderately susceptible) by 75% compared to untreated control vines. Consistent suppression of sour rot was obtained by weekly to twice-weekly nighttime applications of UV-C at 200 J/m^2. UV-C applications produced no deleterious effects as indicated by 20 metabolic responses, as well as measurements of berry size, berry number per cluster, berry weight, cluster weight, yield per ha, fruit soluble solids, leaf size, leaves per shoot, and shoot length. Preliminary data indicate minimal persistent effects of nighttime UV-C applications on epiphytic microflora.

Keywords: Grapevine diseases, ultraviolet light, germicidal UV, UV-C

1. Introduction

Microbial plant pathogens can persist in an environment of direct sunlight partly due to their ability to repair UV-inflicted damage to their DNA through a robust photolyase mechanism driven by blue light and UV-A (Suthaparan et al 2014). This link between sunlight and the ability to withstand exposure to UV-B has been exploited by exposing plants to fungicidal doses of UV-B or equivalent doses of germicidal UV-C during darkness. When damage to fungal DNA is not repaired within 4 hrs after exposure to UV, it is lethal to a large percentage of the exposed population (Suthaparan *et al* 2012, Janisiewicz *et al* 2016). 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. 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* 1992, 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*.

The adaptation of nighttime UV-C treatments to commercial field plantings has necessitated the development of UV lamp 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*). This apparatus contained two hemicylindrical arrays of UV-C lamps and was the basis of a later array design fitted to an autonomous robotic carriage (Onofre *et al* 2021). UV-C treatments applied once or twice weekly at doses from 70 to 200 J/m^2 effectively suppressed strawberry powdery mildew to a degree that equaled or exceeded that of some of the best available fungicides (Onofre *et al* 2021). A long-term goal of our research is to develop light-based disease suppression technology for other crops.

Fungicidal suppression of many pathogens of specialty crops can be problematic. Resistance to many fungicide classes, including sterol demethylation inhibitors (DMI), strolbilurins, bezimidazoles, and succinate dehydrogenase inhibitor (SDHI) fungicides is sufficiently widespread that the forgoing classes are no longer effective on some crops. If nighttime UV-C treatments could obviate the threat posed by certain pathogens in these regions, the need for fungicide applications might be substantially reduced. In particular, the potential for nighttime UV-C treatments to remove the threat of powdery mildews would improve options for the remaining members of a pathogen complex due to the differential spectrum of activity of various fungicide classes and different infection requirements for powdery mildews vs other fungi and oomycetes. Availability of a non-fungicidal option for suppression of powdery mildew, to both reduce the selection for resistance and allow optimization of fungicidal suppression of the remaining members of a pathogen complex is therefore desirable. Our goal has been to explore the potential for UV light to suppress a broad range of plant pathogens and pest on a variety of specialty crops.

Winegrapes are severely affected by several fungal plant pathogens, and global wine production is largely based upon the European species *Vitis vinifera L.*; a species with little significant resistance to *Erysiphe necator* (powdery mildew) or *Plasmopara viticola* (downy mildew). The foregoing pathogens are native to North America and are thus evolutionarily-novel to *V. vinifera.* Their management in US winegrape production is especially problematic. This report focuses on the specific aspects of our research on germicidal UV light that are relevant to suppression of grapevine diseases.

2. Material and methods

The UV-C lamp arrays used for our field studies were similar in configuration to those described by Onofre *et al* (2021) for strawberries, but with dimensions adapted for grapevine. Each array consisted of a hemicylindrical or arched arrangement (**Fig. 1**) of low-pressure discharge UV-C lamps (Osram germicidal T8 55W UV-C Medium Bi Pin Base model G55T8/OF), backed by polished aluminum reflectors (Lamar Lighting Lamar XRFP230), and driven at 700 mA (100% output) using a Philips Advance model UV-2S60-M4-LD ballast. Arrays (**Fig. 1**) were moved through plantings either as a tractor-drawn arch or using a fully autonomous robotic carriage (model Thorvald*,* SAGA Robotics, Ås, Norway). Uniformity and intensity of irradiance was confirmed as described by Onofre *et al* (2021) using a UV spectroradiometer (model BTS2048-UV-S, Gigahertz-Optik GmbH). Dosing was established by adjusting ground speed to apply the desired dose in Joules/m^2 based upon the array length and mean irradiance at the center line of the array at a distance of 30 to 60 cm from the periphery of the canopy. For example, given a mean irradiance of 75 W/m^2 under an array, an array length of 1.5 m, and a target dose of 200 J/m^2, ground speed would be adjusted such that the array would require 2.666 seconds to pass over the target, yielding a speed of 1.777 m/s, or 6.397 km/h (75 W/m^2 X 2.666s = 200 J/m^2).

During the period from 2018 to 2021, the UV technology was evaluated for suppression of the following: powdery mildew in grapevine (*Erysiphe necator),* downy mildew in grapevine (*Plasmopara viticola*), sour rot in grapevine (microbial and arthropod complex), and Botrytis bunch rot in grapevine (*Botrytis cinerea*). UV treatments began approximately 30 minutes after sunset. UV treatments were completed within 4 hrs before sunrise the following morning to allow sufficient time after UV exposure for maximum efficacy and to prevent reversal of the damage by activation of DNA repair after sunrise. Frequency of UV application ranged from once to twice weekly and the UV dose per application ranged from 70 to 200 J/m^2.

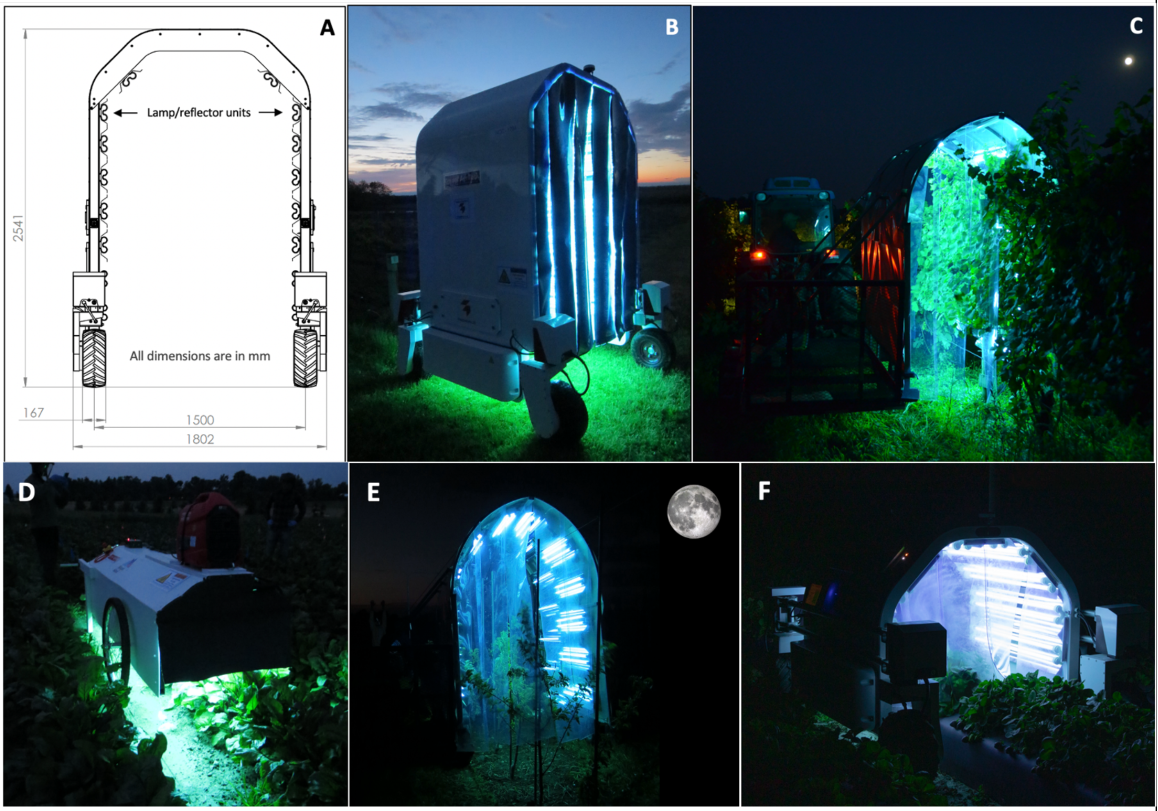

Fig. 1. Various arrays and carriages used to apply UV-C to crops. (A) Dimensions of Saga Robotics "Thorvald" autonomous robotic carriage used in grape trials. (B) Grape version of "Thorvald" at sunset in vineyard. (C) Tractor-drawn UV-C lamp array in vineyard. (D) Small "pushcart" version of UV-C lamp array used for row-crop experiments in beets. (E) Tractor-drawn lamp array in slender-spindle apple orchard for fireblight suppression. (F) Saga Robotics "Thorvald" autonomous robotic carriage in Florida strawberry trials.

3. Results and discussion

Grapevine powdery mildew. Weekly nighttime applications of UV-C at 100 or 200 J/m^2 significantly but equivalently ($P > 0.05$) reduced the severity of powdery mildew on leaves and fruit of Chardonnay grapevines at Geneva, NY in 2019 compared to the untreated control but did not suppress disease as effectively as the fungicide standard. In 2020, all UV-C treatments reduced the severity of powdery mildew in leaves and fruit compared to the untreated control. At doses of 70 or 100 J/m^2, the degree of disease suppression on leaves or fruit was not significantly increased ($P > 0.05$) by applying the dose twice weekly compared to once per week. However, at 200 J/m^2, UV-C applied twice weekly provided significantly better suppression of powdery mildew both leaves and fruit than did once-weekly applications ($P < 0.05$), and the 200 J/m^2 dose applied twice weekly provided suppression of foliar and fruit disease severity that was statistically equivalent ($P > 0.05$) to that provided by the fungicide standard (**Fig. 2**).

In 2020, at a commercial Chardonnay vineyard in Dresden, NY, incidence and severity of powdery mildew was at trace levels in both the grower's fungicide program and weekly applications of UV-C at 200 J/m^2. At the time of veraison in 2020 (13 August), the mean number of powdery mildew-infected leaves per shoot was 0.07 on fungicide-treated vines compared to 0.05 infected leaves per shoot on the UV-C-treated vines. The mean percentage of the leaf surface colonized on infected leaves was 0.33% on fungicide-treated vines compared to 0.23% on vines treated with UV-C. Similar trace levels of powdery mildew were observed among both levels (100 and 200 J/m^2) and frequency of application (once or twice weekly) on Chardonnay vines in Dresden NY in 2021. These results have been recently published elsewhere (Gadoury *et al* 2022).

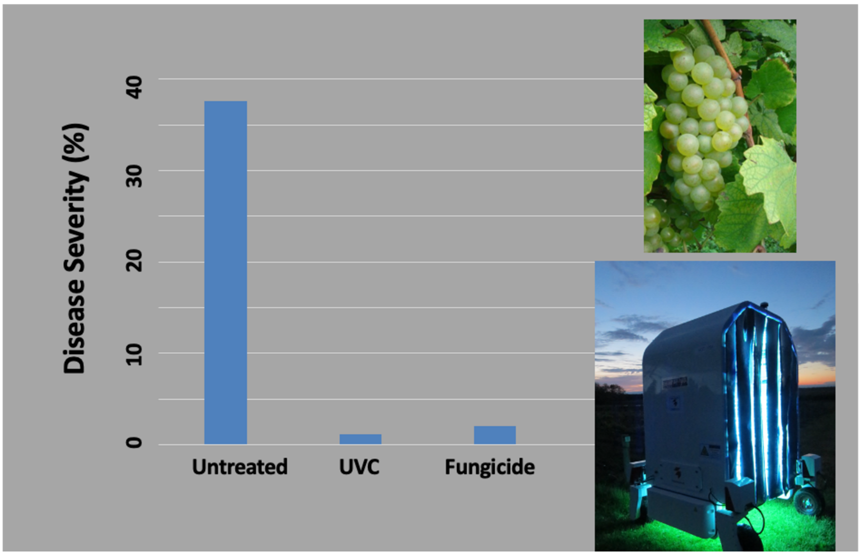

Fig. 2. Suppression of grapevine powdery mildew in 2020 on fruit of Chardonnay by twice-weekly applications of UV-C at 200 J/m^2.

Grapevine downy mildew. No rate or interval of UV-C application significantly reduced the incidence or severity of foliar downy mildew on highly-susceptible Chardonnay grapevines compared to the untreated control. However, on the more downy mildew-resistant cultivar Vignoles, foliar downy mildew was reduced from 1.12 infected leaves per shoot (SE = 0.236) on the untreated control to 0.27 infected leaves per shoot (SE = 0.087) on vines treated twice-weekly with UV-C at 200 J/m^2. These results have been recently published elsewhere (Gadoury et al 2022).

Sour rot and Botrytis bunch rot of grapevine. Weekly applications of UV-C at 200 J/m^2 provided excellent suppression of sour rot on the *Vitis* interpecific hybrid cultivar 'Vignoles' compared to the fungicide standard used in 2019 (**Fig. 3**). However, UV-C did not provide significant suppression of *Botrytis* bunch rot. In 2021, twice-weekly application of UV-C at 200 J/m^2 also provided significant suppression of sour rot on Vignoles grapevines compared to untreated vines. These data have been recently published elsewhere (Gadoury *et al* 2022).

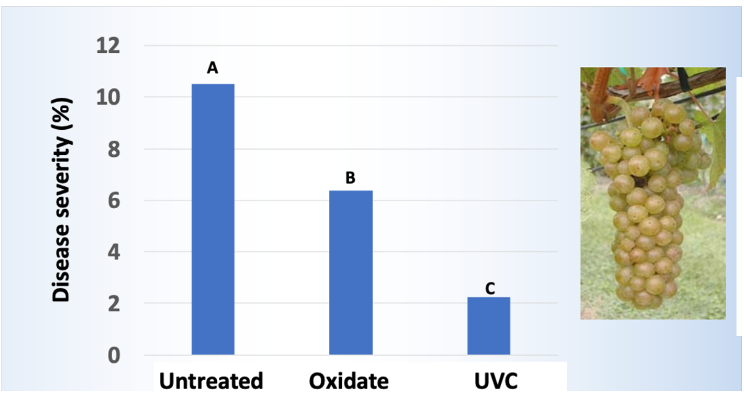

Fig. 3. Suppression of the sour rot complex on the *Vitis* interspecific hybrid cultivar Vignoles by twice-weekly applications of UV-C at 200 J/m2

4. Conclusions

Nighttime application of UV-C at doses ranging from 100 to 200 J/m2, and at frequencies of once- to twice-weekly have provided excellent and commercially-relevant levels of suppression of powdery mildew and sour rot under severe disease pressure, and have provided useful levels of partial suppression of downy mildew. To date, UV-C has not provided significant suppression of Botrytis bunch rot, but research is continuing in this area and recent successes against Botrytis in other pathosytems (strawberry) may bode well for it eventual use in viticulture. Even at the highest doses and most-frequent intervals of application, UV-C did not affect a broad range of growth indices, common fruit and juice-quality parameter, or 20 different metabolic responses associated with host growth, photosynthesis, electron transport, or stress metabolism. UV-C is a safe and effective tool that can be added to existing IPM programs to provide a more robust and sustainable program to promote plant health.

5. Acknowledgments

The authors are grateful for the creativity and imagination of the late **Alfred J. Michaloski**, who first approached the corresponding author with the crazy idea that germicidal lamps might control grape powdery mildew in 1991 (see US Patent Number 5,040,329). This research was primarily supported by the **USDA Organic Research and Extension Initiative** award number 2015-51300-24135, with additional support from the **New York Wine and Grape Foundation**, **John Martini** at Anthony Road Wine Company of Dresden, NY, **Greg and Lillian Taylor** at Bully Hill Vineyards of Hammondsport, NY, and **Saga Robotics LLC**. The authors are grateful for the excellent technical assistance of **Mary Jean Welser**, **David Combs**, **Camille Sisto**, and **Julia Steele**, additional research by Dr. **Surya Sapkota** and **Anna Underhill**, and for the groundwork studies and valuable conversations of our colleagues in the Light and Plant Health group: Drs. Mark Rea and Mariana Figueiro of Mount Sinai Research Hospital, Drs. **Arne Stensvand** and **Aruppillai Suthaparan** of the Norwegian University of Life Sciences, Dr. **Jan Nyrop** at Cornell University, Drs. **Natalia Peres** and **Rodrigo Onofre** of the University of Florida Gulf Coast Research and Education Center, Dr. **Michelle Moyer** at Washington State University's Irrigated Agriculture Research and Education Center and Dr. **Walt Mahaffee**, USDA-ARS, Corvallis Oregon.

6. Literature cited

Austin, Craig N., & Wilcox, W. F. 2012. Effects of sunlight exposure on grapevine powdery mildew development. Phytopathology 102:857–866. https://doi.org/10.1094/PHYTO-07-11-0205

Buxton, E. W., Last, F. T., & Nour, M. A. (1957). Some effects of ultraviolet radiation on the pathogenicity of *Botrytis fabae*, *Uromyces fabae* and *Erysiphe graminis*. J. Gen. Microbiol. 16:764–773.

Darras, A. I., Bali, I., & Argyropoulou, E. 2015. Disease resistance and growth responses in *Pelargonium×hortorum* plants to brief pulses of UV-C irradiation. Scientia Horticulturae, 181:95–101. https://doi.org/10.1016/j.scienta.2014.10.039

Gadoury, D. M., Pearson, R. C., Seem, R. C., Henick-Kling, T., Creasy, L. L., and Michaloski, A. 1992. Control of fungal diseases of grapevine by short-wave ultraviolet light. (Abstr.) Phytopathology 82:243.

Gadoury, D.M., Sapkota, S., Cadel-Davidson, L., Underhill, A., McCann, T., Gold, K., Gambhir, N., and Combs, D. 2022. Effects of Nighttime Applications of Germicidal Ultraviolet Light upon Powdery Mildew (*Erysiphe necator),* Downy Mildew (*Plasmopara viticola*), and Sour Rot of Grapevine. https://doi.org/10.1094/PDIS-04-22-0984-RE

Janisiewicz, W. J., Takeda, F., Glenn, D. M., Camp, M. J., and Jurick, W. M. (2016a). Dark period following UV-C treatment enhances killing of *Botrytis cinerea* conidia and controls gray mold of strawberries. Phytopathology 106:386–394. https://doi.org/10.1094/PHYTO-09-15-0240-R

Kunz, B. A., Dando, P. K., Grice, D. M., Mohr, P. G., Schenk, P. M., & Cahill, D. M. 2008. UV-C-induced DNA damage promotes resistance to the biotrophic pathogen *Hyaloperonospora parasitica* in Arabidopsis. Plant Physiol. 148:1021–1031. https://doi.org/10.1104/pp.108.125435

Ledermann, L., Daouda, S., Gouttesoulard, C., Aarrouf, J., and Urban, L. 2021. Flashes of UV-C light stimulate defenses of *Vitis vinifera* L. 'Chardonnay' against *Erysiphe necator* in greenhouse and vineyard conditions. Plant Dis. 105. Doi.org/10.1094/PDIS-10-20-2229-RE.

Osakabe, M. 2021. Biological impact of ultraviolet-B radiation on spider mites and its application in integrated pest management. Appl. Entomol. Zool. 56: 139–155.

Onofre, R.B, Gadoury, D.M., Stensvand, A., Bierman, A., Rea, M.S., and Peres, N.A. 2021. Use of ultraviolet light to suppress powdery mildew in strawberry fruit production fields. Plant Dis. 104:0000-0000. https://doi.org/10.1094/PDIS-04-20-0781-RE

Patel, J. S., Radetsky, L., Plummer, T., Bierman, A., Gadoury, D. M., & Rea, M. 2017. Pre-inoculation treatment of basil plants with ultraviolet-B radiation induces resistance to downy mildew. (Abstr.) Phytopathology 107:52.

Suthaparan, A., Solhaug, K. A., Stensvand, A., and Gislerød, H. R. 2016a. Determination of UV-C action spectra affecting the infection process of *Oidium neolycopersici*, the cause of tomato powdery mildew. J. Photochem. Photobiol. 156:41-49.

Suthaparan, A., Stensvand, A., Solhaug, K. A., Torre, S., Telfer, K. H., Ruud, A. K., Mortensen, L. M., Gadoury, D. M., Seem, R. C., and Gislerød, H. R. 2014. Suppression of cucumber powdery mildew by supplemental UV-B radiation in greenhouses can be augmented or reduced by background radiation quality. Plant Dis. 98:1349-1357.

Suthaparan, A., Stensvand, A., Solhaug, K. A., Torre, S., Mortensen, L. M., Gadoury, D. M., and Gislerød, H. R. 2012a. Interruption of the night period by UV-B suppresses powdery mildew of rose and cucumber. Acta Hortic. 956:617-620.

Suthaparan, A., Stensvand, A., Solhaug, K. A., Torre, S., Mortensen, L. M., Gadoury, D. M., Seem, R. C., and Gislerød, H. R. 2012b. Suppression of powdery mildew (*Podosphaera pannosa*) in greenhouse roses by brief exposure to supplemental UV-B radiation. Plant Dis. 96:1653-1660.