Reducing Powdery Mildew in High-tunnel Tomato Production in Oregon with Ultra Violet-C Lighting

Kristine R. Buckland[1], Cynthia M. Ocamb[2], Ann L. Rasmussen[1], and Lloyd L. Nackley[1]

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ABSTRACT. **Widespread outbreaks of tomato powdery mildew (*Leveillula taurica* and *Oidium neolycopersici*) are problematic in fresh market tomato (*Solanum lycopersicum*) crops in western Oregon, USA. In western Oregon, fresh market tomatoes are frequently grown in greenhouses or high tunnels where conditions can promote diseases such as powdery mildew. Heightened concerns about worker safety limit the pesticides available for use in enclosed systems. We studied the efficacy of ultraviolet-C (UV-C) light applications under high-tunnel conditions compared with a standard fungicide program. Plants treated with UV-C had zero incidence of powdery mildew on all sample dates in the first trial. In trial 2, disease incidence was lower on UV-C treated plants than both grower standard and nontreated control early in the study while disease severity remained lower in UV-C than nontreated control and similar to grower standard treatment. Additional research is needed to optimize UV-C treatment intervals to minimize negative effects on plant growth and maximize powdery mildew control.**

Fresh market tomatoes (*Solanum lycopersicum*) in the Pacific Northwest region of the United States are mostly grown under plastic or greenhouse systems. Recent outbreaks of tomato powdery mildew, incited by *Leveillula taurica* and *Oidium neolycopersici*, limit production because severe disease leads to defoliation of plants (Kiss et al. 2001, 2005). Chemical control options exist, yet many growers avoid pesticide use due to worker safety concerns. Alternatively, certain ultraviolet (UV) light wavelengths have been used to reduce powdery mildew in other crops (Janisiewicz et al. 2016; Suthaparan et al. 2014, 2016, 2017), but limited research exists for tomato production systems. We hypothesized that UV-C light would provide effective control of tomato powdery mildew in high-tunnel tomato production.

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[1]North Willamette Research and Extension Center, Oregon State University, Aurora, OR 97002, USA

[2]Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331, USA

K.R.B. is the corresponding author. E-mail: kristine.buckland@oregonstate.edu.

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Materials and methods

Two replicate trials were conducted in 2020 in a high-tunnel at the Oregon State University North Willamette Research and Extension Center located near Aurora, OR, USA. The high-tunnel (30 ft × 96 ft × 8 ft) was covered with a double wall of 4-mil anticondensation polyethylene with no supplemental lighting or heating. Seeds of ‘Cherokee Purple’ tomato were sown on 16 Mar and 26 Jul; plants were transplanted by hand on 13 May and 20 Aug. Treatments included a nontreated control (NTC), a grower standard (STD) of potassium bicarbonate (Milstop; BioWorks, Victor, NY, USA), and UV-C arranged in a randomized complete block design with four replicates. Each replicate plot consisted of 10 plants in two 12-ft-long rows with 2 ft between rows and 1 ft between plants. Two nontreated tomato plants served as buffers between plots. Standard production inputs of fertilizer and drip irrigation were used. All plants were confirmed free of powdery mildew on 22 Jun and 22 Sep, then a 1-gal potted tomato infected with *O. neolycopersici* was placed at one end of each block.

Treatments commenced on 23 Jun and 21 Sep for trials 1 and 2, respectively. Applications of UV-C were made by three lights [2 ft × 0.5 ft (CleanLight XL; CleanLight, Naaldwijk, The Netherlands)] producing broadband ultraviolet-C at 253.7 nm. Two lights were vertical (parallel with plant stems), and the third light was on a horizontal arm over the plant canopy (Fig. 1A). Light was applied to individual plants due to the short effective range of UV-C. Worker safety is critical with UV-C lighting. Precautions included safety shields on lights, long sleeves and gloves, and protective eyewear. Plants in each plot received UV-C treatments twice per week (3- to 4-d intervals). During trial 1, plants received 90 s of UV-C for the first two treatments, then time was reduced to 60 s for 3 weeks more due to observed phytotoxicity presenting as leaf deformity and necrosis (Fig. 1B); UV-C treatment (60 s) was applied twice per week in

Fig. 1. (A) Hand-constructed stand cart (5 ft tall) used for ultraviolet-C (UV-C) treatments in 2020 contained three UV lights [2 ft × 0.5 ft (CleanLight XL; CleanLight, Naaldwijk, The Netherlands)] that produce broadband UV-C at 253.7 nm; the cart was placed next to and above individual plants for treatment then repositioned for the next plant. (B) Phytotoxicity on a tomato plant after receiving UV-C light for 90 s per plant over the first two treatments on 23 and 26 Jun 2020; 1 ft = 0.3048 m.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
9.3540	gal/acre	$L \cdot ha^{-1}$	0.1069
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
0.0254	mil(s)	mm	39.3701

Table 1. Incidence and severity of powdery mildew on tomato in 2020 in trials 1 and 2.

Trial 1							
	Avg powdery mildew incidence (%)						
Treatment[i]	30 Jun	7 Jul	14 Jul	21 Jul	28 Jul	Plant ht (m)[ii]	Fruit (no.)
NTC	0 a	56.25 a	100 a	100 a	100 a	1.7 a	9.8 ab
STD	0 a	37.5 a	0 b	65.6 a	87.5 a	1.6 a	9.2 a
UV-C	0 a	0 a	0 b	0 b	0 b	1.5 b	4.4 b
	Avg powdery mildew severity (%)[iii]						
NTC	0 a	0.5 a	2.9 a	11.2 a	32.1 a		
STD	0 a	0.2 a	0 b	0.6 b	1.1 b		
UV-C	0 a	0 a	0 b	0 b	0 c		

Trial 2								
	Avg powdery mildew incidence (%)							
Treatment	6 Oct	13 Oct	20 Oct	27 Oct	3 Nov	10 Nov	Plant ht (m)	Fruit (no.)
NTC	0 a	100 a	100 a	100 a	100 a	100 a	0.9 a	0.2 a
STD	0 a	15.6 b	25 b	90.2 a	100 a	100 a	0.9 a	0.1 a
UV-C	0 a	0 b	0 b	43.8 a	49.1 a	80.4 a	0.8 a	0.2 a
	Avg powdery mildew severity (%)[iii]							
NTC	0 a	4.6 a	15.8 a	26.7 a	46.8 a	62.5 a		
STD	0 a	0.1 a	0.5 b	4.4 ab	12.6 ab	18.6 ab		
UV-C	0 a	0 a	0 b	0.4 b	2.4 b	2.2 b		

[i] NTC = nontreated control; STD = grower standard 4.25 lb/acre (4.764 kg·ha^{-1}) potassium bicarbonate (Milstop; BioWorks, Victor, NY, USA), UV-C = ultraviolet-C applied for 90 s in the first two treatments, 60 s all subsequent treatments. Different letters following the treatment mean within columns indicate significant differences ($P < 0.05$) as determined by the Tukey–Kramer method.
[ii] 1 m = 3.2808 ft.
[iii] Means are based on the percentage of leaf area covered with powdery mildew on 10 compound leaves on each of eight plants with four replicates per treatment.

trial 2. The efficacy of UV-C applications is greater after dark (Suthaparan et al. 2012), so treatments were applied after sunset. The STD was applied weekly at 4.25 lb/acre a.i. in 240 gal/acre water using a handheld sprayer.

The percentage of leaf area with visible powdery mildew (disease severity) was estimated weekly on 10 compound leaves from eight tomato plants within each plot from 30 Jun through 28 Jul (trial 1) and from 7 Oct through 10 Nov (trial 2); on each plant, the oldest leaves without signs of premature senescence were selected for rating. Disease incidence was calculated as the percentage of leaves with visible powdery mildew. Individual leaf ratings from each plant served as subsamples, and the mean was subjected to analysis of variance in statistical software (ver. 9.4; SAS Institute Inc., Cary, NC, USA). Treatment effects on plant vigor were measured as plant height, fruit count, and leaf chlorophyll content of five leaflets [SPAD-502 Plus chlorophyll meter; Konica Minolta, Ramsey, NJ, USA) on two randomly selected plants per plot (30 Jul and 12 Nov for trials 1 and 2, respectively).

Results and discussion

In the first trial, no differences in disease incidence were observed until 14 Jul when both the STD and UV-C plants had zero disease but 100% of the NTC plants had visible disease. The following 2 weeks, UV-C had zero disease incidence, but STD and NTC were higher (Table 1). On the last three dates, STD had less severe infection than NTC while UV-C remained free of disease.

In trial 2, NTC had greater disease incidence than STD and UV-C on both 13 and 20 Oct (Table 1). All treatments reached similar incidence levels the following week. However, disease severity remained low in UV-C throughout the trial and significantly lower than NTC for the last four sample dates. The STD and UV-C disease severity was similar for all dates in trial 2. Results illustrate potential for high-tunnel UV-C applications with similar disease control efficacy as in laboratory settings (Suthaparan et al. 2016).

In the first trial, STD plants were significantly taller with more fruit than UV-C treated plants (Table 1), similar to Sofo et al. (2014), who reported tomato plants were shorter with reduced photosynthesis after UV-C exposure. No differences in height or fruit number were observed in trial 2, likely due to reduced UV-C duration. In both trials, leaf chlorophyll content was not statistically different among treatments (data not shown).

Conclusions

Our trials demonstrate efficacy of UV-C against tomato powdery mildew in high-tunnel production providing an innovative approach to reducing pesticide applications. However, leaf phytotoxicity and reduced fruit set were observed in trial 1. Additional work is needed to refine treatment duration to maximize disease suppression while minimizing negative effects.

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