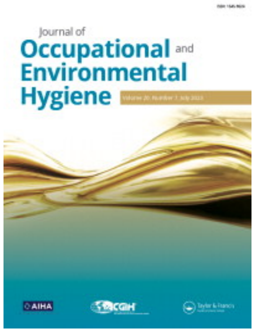

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Ultraviolet radiation exposure in cannabis-growing facilities

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ABSTRACT
Cannabis cultivation and processing is becoming an important industry in the United States and Canada. The industry employs over 400,000 workers in the United States and is growing rapidly. Both natural sunlight and artificial lamp-generated radiation are commonly used to grow cannabis plants. These optical sources can contain both visible and ultraviolet radiation (UVR) wavelengths, and overexposure to UVR is associated with negative health effects. The severity of these adverse health effects is governed by the specific wavelengths and exposed dose of UVR, yet worker exposure to UVR within cannabis-growing facilities has not been studied. In this study, worker exposure to UVR was assessed at five cannabis production facilities in Washington State, including indoor, outdoor, and shade house facilities. Lamp emission testing was performed at each facility and worker UVR exposures were measured for 87 work shifts. Observations of worker activities and use of personal protective equipment in association with UVR exposure measurements were recorded. For lamp emission measurements, at 3 feet from the center of the lamp, the average irradiances were 4.09×10^{-4}, 6.95×10^{-8}, 6.76×10^{-9}, 3.96×10^{-9}, and 1.98×10^{-9} effective W/cm^2 for germicidal lamps, metal halide lamps, high-pressure sodium lamps, fluorescent lamps, and light emitting diodes, respectively. The average measured UVR exposure was 2.91×10^{-3} effective J/cm^2 (range: 1.54×10^{-6}, 1.57×10^{-2} effective J/cm^2). Thirty percent of the work shifts monitored exceeded the American Conference for Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®) of 0.003 effective J/cm^2. Exposures were highest for workers who spent all or part of the work shift outdoors, and solar radiation was the primary source of worker UVR exposure for most of the work shifts that exceeded the TLVs. Outdoor workers can reduce UVR exposure by applying sunscreen and wearing appropriate personal protective equipment. Although the artificial lighting used in the cannabis production facilities included in this study did not contribute substantially to the measured UV exposures, in many cases the lamp emissions would generate theoretical exposures at 3 feet from the center of the lamp that would exceed the TLV. Therefore, employers should choose low UVR emitting lamps for indoor grow operations and should use engineering controls (e.g., door-interlocks to de-energize lamps) to prevent worker exposure to UVR from germicidal lamps.

KEYWORDS
Cultivation; horticulture; indoor; marijuana; non-ionizing radiation; UV

Introduction

Laws permitting the growth and possession of cannabis for medicinal and recreational use are currently changing rapidly in the United States and internationally (Carliner et al. 2017; Caulkins et al. 2018; Mahamad and Hammond 2019). While the cultivation and use of cannabis are still considered illegal by the U.S. federal government, multiple states have legalized the recreational or medical use of marijuana (Carliner et al. 2017). Canada has also recently legalized cannabis use (Mahamad and Hammond 2019). These changes have led to a dramatic expansion of the cannabis industry, which now employs approximately 420,000 workers in the United States, and job growth is among the fastest of any industry in the United States (Borchardt 2017; Barcott et al. 2022). However, in part due to the history of cannabis as an illicit substance, few peer-reviewed studies have investigated the occupational hazards faced by workers in this emerging industry.

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Many cannabis production facilities grow crops using lamp-generated radiation, solar radiation, or a combination of both. A crop cycle typically begins by cloning mother plants and placing the clones in a nursery. Plants in nurseries generally only receive lamp-generated radiation, although some facilities use solar radiation in combination with lamp-generated radiation. Once the plants reach a desired size, workers move them into a "grow area" where the crop completes its growth and flowering stages of life. These grow areas vary between facilities and include greenhouses, shade houses, indoor spaces, or outdoor spaces. Once in full bloom, the crop is harvested and hung to dry in a dark drying room. Finally, the dry product is taken from the drying room to a separate room or facility where the crop is processed into one of the many consumer cannabis products (Simpson 2017; Green et al. 2018; WASAO 2018).

Some lamp types used in the cannabis industry emit ultraviolet radiation (UVR). UVR wavelengths range from 100 to 400 nm and are further classified into UVA (315 to 400 nm), UVB (280 to 315 nm), and UVC (100 to 280 nm) (IARC 2018). The most common UVR overexposure injury is erythema (Hausser 1928; Coblentz et al. 1931), and the most severe erythema is caused by UVB (Hausser 1928; Ichihashi et al. 2003). Various organizations have developed weighting scales to quantify the wavelength dependence of skin damage caused by UVR (CIE 1999; IARC 2018; ACGIH 2022). Two commonly used weighting scales are those from the American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission on Illumination (CIE). All wavelengths of UVR are classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) (Surdu et al. 2013; IARC 2018). Additionally, IARC considers UVB "in the terrestrial solar spectrum to be mainly responsible for adverse health effects" (IARC 2018). UVB exposure has been associated with photokeratitis (Pitts and Tredici 1971), whereas both UVB and UVC overexposure cause keratoconjunctivitis (Pitts et al. 1977). Injury severity is influenced by eye motion, spectral profile, and angle of incoming radiation (ICNIRP 1997).

The ACGIH has published threshold limit values (TLVs), most recently revised in 2022, that represent a 24-hr exposure threshold below which a typical worker should not develop adverse health effects (ACGIH 2022). There is no Federal Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for UVR exposure. The ACGIH 2010 TLVs are the basis for the Washington State Department of Labor and Industries (L&I) UVR PEL (WAC 2003), which restricts occupational exposure to UVR (from sources other than UVR lasers and the sun) to under 0.003 effective J/cm^2 (eff. J/cm^2) per day. This unit, used in both the ACGIH TLVs and the L&I regulations, is a health-weighted measure of UVR exposure. The results presented are weighted to the recently published ACGIH 2022 TLV and corresponding action spectrum, which perfectly matches the ACGIH 2010 action spectrum at all wavelengths above 240 nm.

To maximize worker safety and industry productivity, scientific data must underpin cannabis regulation. In this context, the current study adds to the body of literature through the evaluation of ambient UVR irradiance and UVR exposure at five cannabis production facilities. The work presented here is one of the first studies to assess UVR irradiances in indoor cannabis cultivation facilities, and the first known application of wearable UVR dosimeters to measure worker exposure to UVR in this industry.

Methods

Study setting and subjects

UVR emissions from optical sources were measured and worker UVR exposure was monitored at five cannabis farms across Washington State during multiple visits throughout June to December 2017. Farms were recruited through The Cannabis Alliance, a Washington State-based cannabis business organization. The study was advertised at a regular monthly meeting of The Cannabis Alliance and through their website and email listserve. Three of the farms evaluated in this study grew plants entirely indoors, one used both indoor and shade house spaces, and one used a combination of indoor, greenhouse, and outdoor space.

Only those workers directly involved in cannabis cultivation tasks were eligible to participate in the study. During the first visit to each farm, the study team met with all eligible workers present to recruit them to participate in the study. A total of 22 subjects (between 2–5 subjects per farm) consented to participate and were enrolled in the study.

Enrolled subjects completed a questionnaire that provided information on specific job responsibilities, common work locations, and frequency of wearing personal protective equipment (PPE) such as sunglasses, hats, long-sleeved shirts, and/or gloves while working.

During subsequent visits to all farms (3–6 visits per farm, total visits = 21), the research team collected personal full-shift UVR exposure measurements ($n = 87$ work shifts) on all enrolled subjects present using a wearable UVR dosimeter. The dosimeter was mounted on the back of each worker's neck, as that was expected to be the body part that received the highest exposure. Throughout each shift, one of the research technicians logged worker location, posture, use of PPE, and specific tasks completed. The technician updated the worker activity log approximately every 30 min. At the end of each shift, dosimeters were cleaned to ensure that any dirt or plant resin was removed from the optical surface and workers were consulted to ensure that tasks completed were correctly logged.

Devices

A radiometer was used to measure UVR emissions from optical sources and wearable dosimeters were used to measure worker exposure to UVR. The radiometer was the International Light Technologies (Peabody, MA) 2400 radiometer with sensor attachment (SED240/ACT5/W). The response function for this sensor emulates the ACGIH TLV weighting function and generates a response directly comparable to the 2010 ACGIH TLV and the L&I PEL. Radiometer sensitivity was calibrated by the instrument manufacturer using monochromatic radiation at 270 nm. The radiometer's spectral response function was determined by the instrument manufacturer every 2 nm between 200 and 400 nm using a calibrated laser-driven light source (Energetiq Technology, Inc., Wilmington, MA) and a Triax 180 spectrograph (Horiba Ltd., Kyoto, Japan) (see Figure 1). To account for the spectral mismatch between the radiometer's spectral response and the 2022 ACGIH action spectrum, the CIE 220:2016 method (Sperling et al. 2016) was used to develop two spectral mismatch factors using the ASTM 1.5 (solar spectrum) and a germicidal lamp spectrum as test spectra and an equal-energy source as the reference spectrum. The factor based on solar radiation (value = 0.272) was applied to measurements of emissions from MH, HPS, LED, and FL lamps. The other factor was applied to measurements of germicidal lamp emissions (value = 1.054). The radiometer's limit of detection (LOD) was 2.4×10^{-8} eff. W/cm^2 after application of the spectral mismatch factor for solar radiation.

Five wearable UVR dosimeters were purchased from Dr. Martin Allen from the University of Canterbury in Christchurch, NZ. The radiation sensor in these devices is an AlGaN photodiode with a spectral response function that is similar to the CIE action spectrum for inducing erythema in humans (Seckmeyer et al. 2012). The CIE function applies to wavelengths between 250 and 400 nm. The two functions and the spectral response function of our SED240/ACT5/W sensor are presented in Figure 1.

The dosimeter sensor is housed behind a polytetrafluoroethylene diffuser that approximates a cosine-weighted angular response. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) specifies that measurements of UVR exposure to the skin should be made over an angle of 180° using a detector with a cosine weighted angular response (ICNIRP 2007), whereas ACGIH specifies an unweighted angular response with the field of view restricted to 80°. Upon receiving radiation, the sensor generates a signal which is then amplified and sent to the processor. This processor digitizes the signal and records the data in the dosimeter's internal storage. The performance of the UVR dosimeters has previously been evaluated in comparison to a reference spectroradiometer (RS) that complied with the requirements for Network for the Detection of Atmospheric Composition Change instruments and with the requirements for type 2 instruments published by the World Meteorological Organization (Sperling et al. 2016). This validation study showed that after calibration, the UVR dosimeters showed mean absolute deviations of 15% (maximum 33%) from the RS measurements around noon during several test days in the northern hemisphere autumn. This dosimeter has also been used successfully in previous studies to measure personal exposure to UVR from the sun (Allen and McKenzie 2005). These devices have a limit of detection of roughly 2.97×10^{-8} eff. W/cm^2. However, the UVR irradiances at the indoor cannabis farms were often below the detection limit for these dosimeters. Therefore, after exposure monitoring at the first two facilities was complete, the research team purchased three additional enhanced sensitivity wearable UVR dosimeters of the same make and model as the regular dosimeters, but with the internal amplifier setting adjusted by the manufacturer to provide a limit of detection of roughly 1.04×10^{-8} eff. W/cm^2. These devices achieve a lower limit of detection by amplifying the sensor signal ten-fold compared to the other five devices, however, the upper limit of quantification is simultaneously reduced ten-fold. A sensitive device was co-located with a regular device on the back of a worker's neck

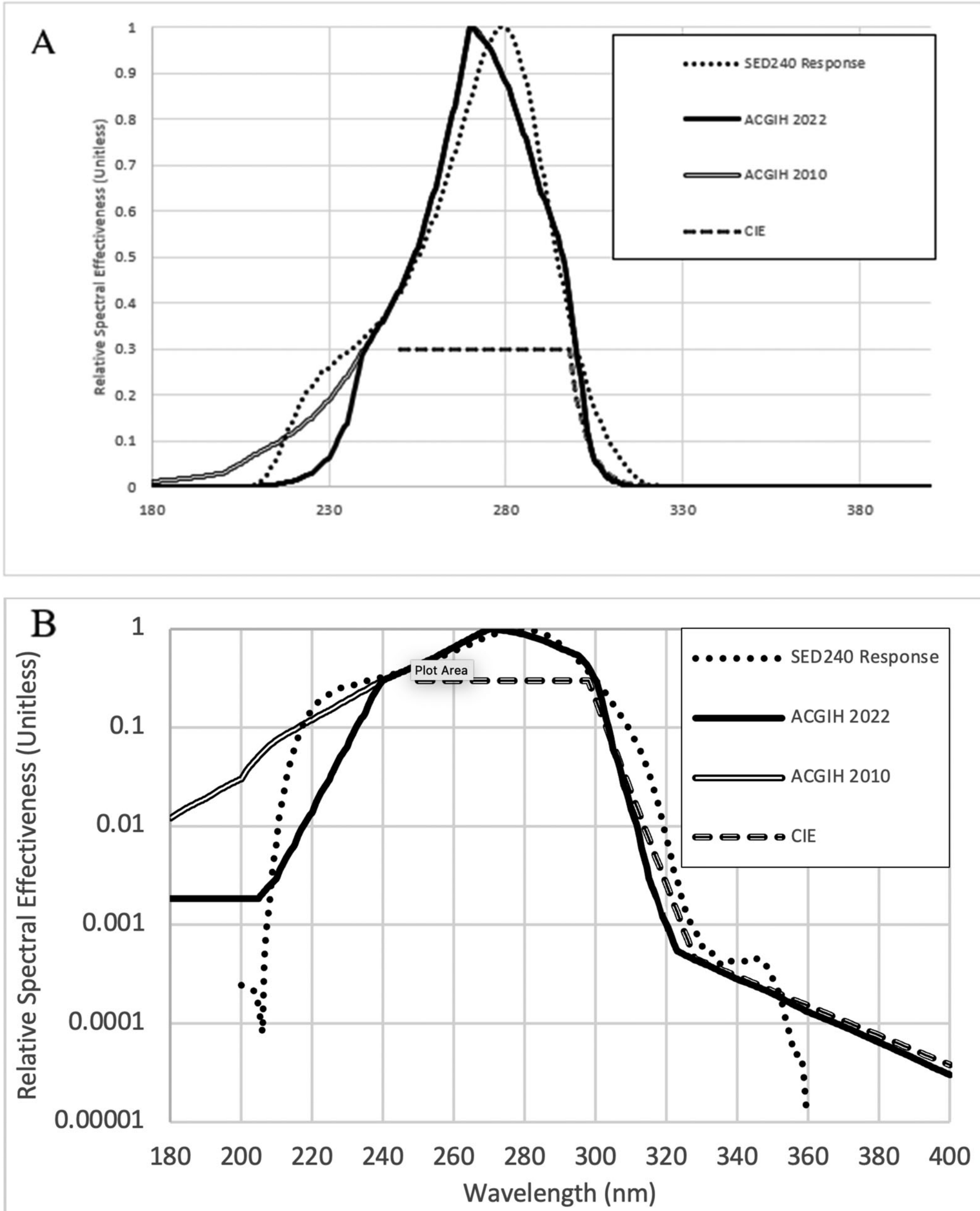

Figure 1. Comparison of the ACGIH 2010, ACGIH 2022, CIE, and SED240/ACT5/W response functions presented in linear (A) and log (B) scales (ACGIH 2022; CIE 1999).

at Facility Five due to the low light conditions present at that facility.

Calibration of UVR dosimeter response to effective W/cm²

The dosimeter's raw signal was converted to units of eff. W/cm^2 by generating and applying a conversion factor for each dosimeter. The data used to generate the conversion factor were obtained by co-location of the radiometer and dosimeters to measure solar radiation. Solar radiation was selected as the calibration spectrum because solar radiation encompasses a wide and continuous range of UVR wavelengths, has day-to-day consistency, and is the likely cause of many of the high exposures observed in this study. These measurement sessions lasted for a minimum of 20 min and included measurements at sunrise and sunset when UVR levels were changing rapidly, to capture a wide range of UVR irradiances for the calibration curve. Data were logged at a sampling rate of one measurement per second, with the radiometer and all dosimeters oriented vertically. Three sessions used both the regular and enhanced sensitivity dosimeters and an additional three sessions only used the regular dosimeters. Spectral correction factors were applied to

Table 1. UVR emissions (eff. W/cm^2) measured at 3 feet from the center of lamps.

Type	# of Lamp Types Tested	Min (eff. W/cm^2)	Max (eff. W/cm^2)	Mean (eff. W/cm^2)	SD (eff. W/cm^2)	Time to Exceed TLV (min)	Percentage at or above LOD
Germicidal	2	2.34×10^{-4}	5.85×10^{-4}	4.09×10^{-4}	2.48×10^{-4}	0.12	100
CMH	8	3.30×10^{-9b}	1.59×10^{-7}	6.95×10^{-8}	7.39×10^{-8}	720	100
HPS	9	<LOD[a]	2.31×10^{-8b}	6.76×10^{-9b}	7.56×10^{-9}	Would not exceed	44
Fluorescent	7	<LOD[a]	1.65×10^{-8b}	3.96×10^{-9b}	5.53×10^{-9}	Would not exceed	14
LED	14	<LOD[a]	2.64×10^{-9b}	1.98×10^{-9}	2.79×10^{-10}	Would not exceed	14

[a]One foot measurement below radiometer limit of detection.
[b]Irradiance at 3 feet was below radiometer LOD of 2.4×10^{-8} (eff. W/cm^2). Value presented is estimated at 3 feet using the inverse square law, from measurements made at 1 foot from the lamp center.

the radiometer measurement values. Outliers and measurements with a dosimeter response of zero were removed from the data set. Each dosimeter's data were plotted as the dependent variable against the radiometer data and a linear regression forced through zero was used to generate calibration coefficients for each dosimeter. Finally, the limits of detection for each dosimeter (in eff. W/cm^2) were calculated from the calibration curve as described by Harris (2006) and verified by visual inspection of the calibration data.

Lamp measurements

The farms visited employed a variety of lighting technologies, including germicidal lamps, high-pressure sodium (HPS) lamps, ceramic Metal Halide (CMH) lamps, light-emitting diodes (LED), and fluorescent lamps. The radiation emissions of each lamp make and model encountered at the five cannabis farms were measured. Emissions from various lamp models at a cannabis business convention (Cannacon) in Seattle, WA, and at a specialty lamp store that supplies many of the local cannabis growers were also measured. These additional measurements provided a wider variety of lamp makes and models to better characterize the range of UVR emissions from the different lighting technologies used in cannabis cultivation. During the measurement of lamp emissions, the sensor field of view was restricted with an optically absorbent 3 in by 1 ft pipe, which resulted in a field of view of 14.25°. If the lamp emission irradiance at 3 ft was below the radiometer LOD, the same setup was to measure the irradiance at 1 ft from the lamp center and use the inverse square law to estimate the emission irradiance at 3 ft.

Data analysis

Lamp emission measurements were aggregated to calculate the mean emission irradiance for each of the five lamp types encountered during the study. For the calculation of summary statistics, emissions measurements below the LOD were substituted with LOD/$\sqrt{2}$. As specified by the ACGIH TLV, the mean emission irradiances were then divided into 0.003 eff. J/cm^2 to determine the corresponding time of overexposure for each lamp type.

Exposure monitoring summary statistics are presented by facility. A two-sample, two-tailed t-test assuming unequal variance was used to compare the mean average radiant exposure for indoor and outdoor shifts.

Data management and statistical analyses were performed using Microsoft Excel (Version 2013, Microsoft Corp., Redmond, WA) and the R-programming language (Version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria).

Results

Lamp emission measurements

The irradiance of UVR emissions varied by lamp type and is summarized in Table 1. Germicidal lamp models emitted the highest UVR irradiances by three orders of magnitude, with a mean of 4.09×10^{-4} eff. W/cm^2. The mean irradiances for CMH lamps, HPS lamps, fluorescent lamps, and LED lamps were 6.95×10^{-8}, 6.76×10^{-9}, 3.96×10^{-9}, and 1.98×10^{-9} eff. W/cm^2, respectively. These values correspond to overexposure times of 0.12 min for germicidal lamp emissions and 720 min for metal halide lamp emissions. The corresponding overexposure durations for the other three lamp-type emissions were over 1440 min (24 hr) and therefore would not exceed the ACGIH TLV or the L&I PEL.

Exposure monitoring

Full shift UVR exposures were measured on 22 workers at the five facilities, for a total of 87 work shifts, as shown in Table 2. The average exposure accumulated during a work shift was 2.91×10^{-3} eff. J/cm^2 (range: 1.54×10^{-6} to 1.57×10^{-2} eff. J/cm^2; SD: 3.31×10^{-3} eff. J/cm^2). The average work shift was 438 min

Table 2. Summation statistics by facility.

Facility ID	Primary optical source	# of workers	# of shifts	% of shifts over TLV	Average Daily Radiant Exposure (eff. J/cm^2)	SD (eff. J/cm^2)	Max Radiant Exposure (eff. J/cm^2)	Shift Duration Mean (min)
1	HPS/LED	5	14	0	1.01×10^{-3}	7.28×10^{-4}	2.36×10^{-3}	463
2	LED	3	8	0	3.25×10^{-4}	4.90×10^{-4}	1.30×10^{-3}	475
3	Solar[a]	5	29	24%	2.61×10^{-3}	1.56×10^{-3}	7.31×10^{-3}	434
4	Solar[b]	5	29	66%	5.53×10^{-3}	4.25×10^{-3}	1.57×10^{-2}	446
5	HPS/Fluorescent	4	7	0	9.09×10^{-5}	5.32×10^{-5}	1.62×10^{-4}	305

[a]Greenhouse.
[b]Outdoor.

(range: 161 to 551 min; SD: 97 min). For 30% of the work shifts, the worker's accumulated UVR exposure exceeded 0.003 eff. J/cm^2 ACGIH TLV.

Facilities 1, 2, and 5 grow plants indoors and exclusively use lamp-generated radiation, while facilities 3 and 4 grow plants outdoors or in greenhouses. Plants grown outdoors only received solar radiation while plants grown in greenhouses received both solar and lamp-generated radiation. Work shifts performed in facilities that exclusively used lamp-generated radiation ($n = 29$) had a mean exposure of 5.98×10^{-4} eff. J/cm^2, which was significantly lower than shifts performed in facilities that primarily used solar radiation ($n = 58$; mean exposure of 3.58×10^{-3} eff. J/cm^2; $p < 0.01$).

Figure 2A illustrates a typical time series of UVR exposure during a single work shift for a worker at an indoor cannabis farm. This work shift contained one period of elevated UVR exposure between 12:50 and 13:20, which accounts for 99% of the total UVR exposure measured during this work shift. During this 30-min interval, the subject's activity log indicates the worker was taking an outdoor lunch. Figure 2B illustrates a typical time series of UVR exposure during a single work shift for a worker at an outdoor cannabis farm. The time series illustrates a period of elevated UVR exposure between 8:30 am and 12:30 pm while the subject was working outside. The UVR irradiance tended to increase during this period as the sun rose higher in the sky. After 12:30 pm this worker moved indoors to work trimming cannabis flowers under regular fluorescent lighting. Their UVR exposures were largely undetectable during this time, except for a brief period between 13:30–13:40 when the worker took a break outdoors under a canvas sunshade.

Discussion

Lamp emission measurements

Powdery mildew is frequently encountered in cannabis farms (Scott and Punja 2021). However, the chemicals approved for use on cannabis in Washington State (WSDA 2018) are not especially effective in controlling powdery mildew. Consequently, germicidal lamps are being marketed to cannabis farms as a tool to control powdery mildew. Table 1 shows that germicidal lamps produce UVR at irradiances that could cause overexposure in under 30 sec. The irradiances measured create a health risk that is not well recognized in the cannabis industry, and germicidal lamp manufacturers do not consistently provide this information on lamp packaging (Solacure 2016)

Non-germicidal lamps encountered during the study were LED, HPS, fluorescent, and MH lamps. MH lamps produced the highest levels of effective UVR among these four lamp categories on average, but at least one lamp of each type produced effective UVR at irradiances detectable by the radiometer. A variety of factors influence grower choice of lighting technologies, and lighting practices are not standardized across the industry. The use of solar radiation for cannabis cultivation is common in areas where climate and local regulations are conducive to growing cannabis outdoors, although in these settings, supplemental use of artificial light can extend the growing season. For indoor grows, a variety of factors influence the lighting technology used. These factors may include purchase and operating costs, availability of energy efficiency incentives that promote the use of LED lamps, and individual grower beliefs about which lighting technology promotes desirable characteristics in their product.

Uncertainty associated with UV dosimeter calibration

The UVR dosimeter measurements were calibrated with solar radiation using the ILT radiometer as the reference instrument to convert the dosimeter response into units that correspond to the ACGIH action spectrum, as described in the methods section. Figure 3 illustrates the calibration data for one dosimeter, aggregated from six calibration experiments undertaken on separate days. Linear relationships between the radiometer and the dosimeter were

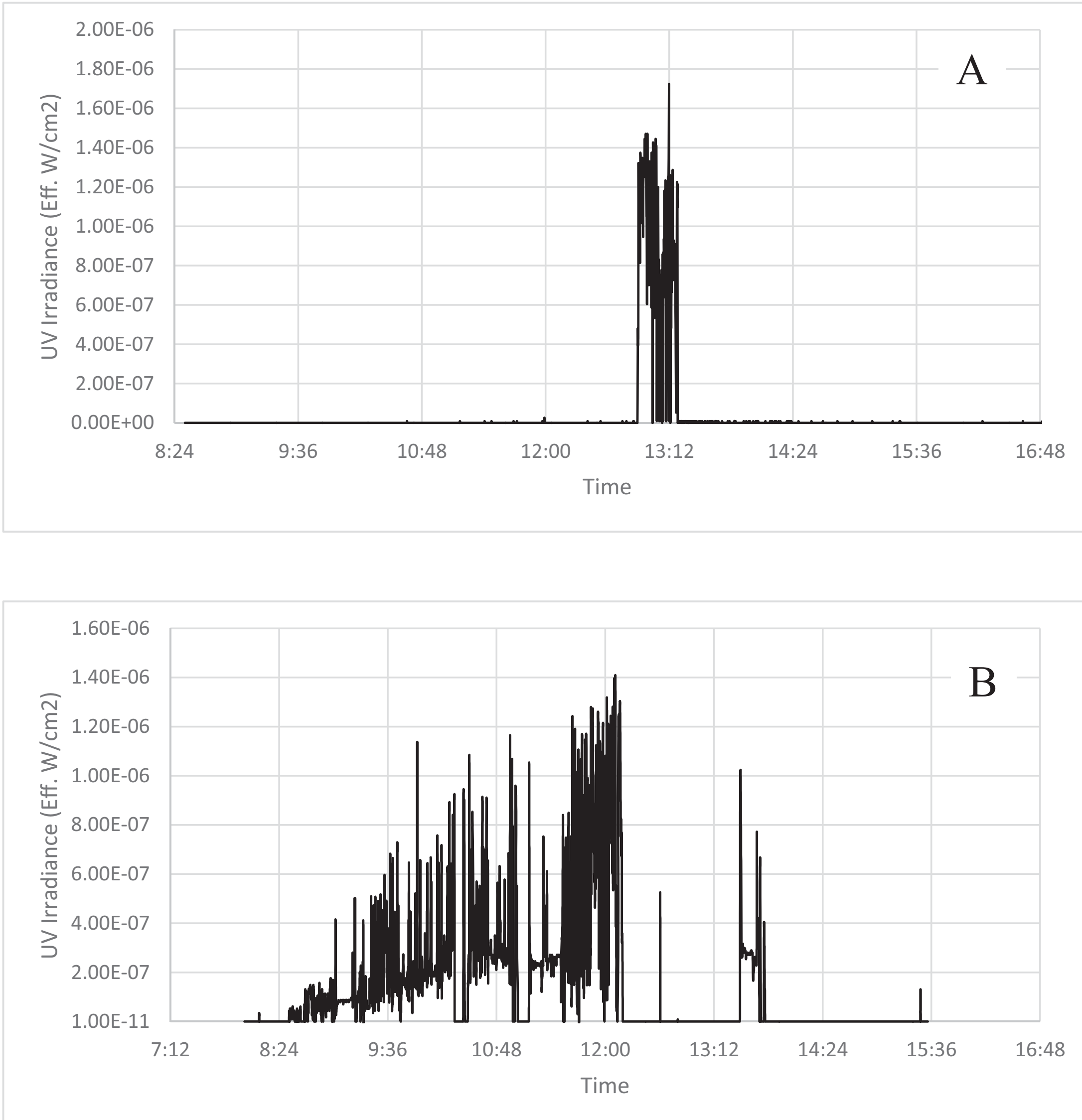

Figure 2. Typical time series of workers' UVR exposures. Panel A: Worker at an indoor facility. Panel B: Worker at an outdoor facility.

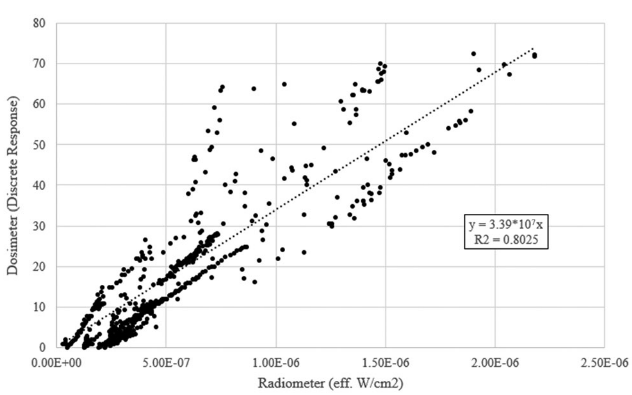

Figure 3. Plot of the calibration data for one dosimeter, aggregated across six calibration experiments, including the linear regression forced through zero. Each dot represents the average irradiance recorded over a 1-min interval.

observed for all eight dosimeters, with the R^2 of the linear regression ranging between 0.80 and 0.87. Variation in the calibration relationship is likely due to variations in measurement angle, atmospheric conditions, and ambient temperature. Of these, measurement angle is probably the most significant source of variability because the radiometer and dosimeters have different angular response functions.

Atmospheric conditions such as airborne particulate matter, cloud density, and humidity impact the day-to-day irradiance and spectrum of solar radiation. Variations in the solar spectrum may differentially affect device measurements because the radiometer has a different wavelength-dependent response function compared to the dosimeters. Temperature changes may also have differentially affected instrument response, however, this effect is probably minimal because all sessions took place within the acceptable manufacturer-provided temperature range.

The use of solar radiation to calibrate the dosimeters adds uncertainty to the calibration relationship when measuring UVR from non-solar sources. The spectra of lamp-generated radiation vary greatly by lamp make and model and can be very different from the solar spectrum. These spectral mismatches may cause bias in the dosimeter measurements of unknown magnitude and direction. Unfortunately, to our knowledge, no low-cost wearable UVR exposure sensors are commercially available that perfectly emulate the hazard function specified in the Washington State PEL, which is identical to that of the ACGIH 2010 TLV.

The dosimeter's cosine response and 180° field of view are appropriate for the measurement of UV exposure to the skin, but not the eye, per the ICNRP guidance. (ICNIRP 2007) The dosimeter measurement likely overestimates the measurement of irradiance relative to the ACGIH prescription for measurement which stipulates an 80° field of view and no angular weighting. The Washington state regulation that specifies the PEL for nonionizing radiation does not specify either a field of view restriction or an angular weighting for UV measurement. (WAC 2003) The inconsistency amongst these various organizations in their guidance for measuring UVR exposure creates challenges for both UV dosimeter manufacturers and users.

Exposure monitoring

Twenty-six of the 87 work shifts monitored (30%) had UVR exposures exceeding the ACGIH TLV. All 26 occurred at facilities where the primary optical source was solar radiation. Furthermore, the contribution of lamp-generated radiation to exposures was not readily discernable. The UVR exposure time series for the indoor worker shown in Figure 2A illustrates this issue; 99% of the total UVR exposure for this work shift occurred between 12:50 and 13:20 (Pacific Time Zone, U.S.), while the worker was on their lunch break outdoors and away from lamp-generated radiation. In contrast, during most of the work shifts at this facility when the workers were indoors under artificial light, UVR exposures were undetectable. The portion of UVR exposure attributable to lamp-generated radiation is important from a regulatory compliance perspective because the Washington State UVR PEL does not apply to solar radiation. In our data, UVR exposure attributable to solar radiation is not easily separable from the UVR exposure attributable to lamp-generated radiation because the granularity of our task activity logs was not adequate to capture each instance of solar radiation exposure. Incident radiation geometry may influence the target organ receiving the UVR dose. The location and orientation of the human eyes are well adapted to the position of the sun overhead. However, the human eye is not adapted to optical sources in the plane of sight (Sliney 2001). Thus, indoor workers may receive a larger proportion of UVR dose to the eyes relative to the skin when compared to outdoor workers. Regarding the effects of UVR exposure on the skin, the health implications of any UVR dose received will vary based on individual susceptibility (skin phototypes) and adaptation to UVR exposure (e.g., tanning).

UVR exposure variability within and between shifts is likely due to a variety of environmental and personal factors. Environmental factors include variation in solar irradiance and cloud cover, worker location (outdoors vs. indoors), use of various lamp models, radiation pathway interference, lamp height, and resin accumulation on dosimeter optical surfaces. The irradiance of lamp UVR emissions varied greatly within and between each of the five lamp types. Of the five lamp types, germicidal lamps emitted the highest effective UVR on average. In comparison, except for one model, the LED lamps that were tested in this study emitted no detectable UVR, even at a measurement distance of 1 ft. However, given that UVR emitted from one LED model tested in this study, the data demonstrate that LEDs can be designed to produce UVR. Furthermore, some lamp manufacturers specifically market UVR-emitting LED lamps for use in cannabis cultivation. Forty lamp models were measured throughout the study, never encountering the same lamp model at multiple farms. The variation in lamp models likely creates a range of ambient UVR irradiances, which may increase the variability of UVR exposure over multiple shifts. Radiation pathway interference is caused by plant foliage and other objects in a growing area obstructing the path between the optical source and the dosimeter. A packed grow area is less porous to the transmission of UVR and will likely reduce worker UVR exposure. In the indoor facilities, worker UVR exposures were affected by lamp height; the further away a lamp is from a worker, the lower the UVR exposure. Finally, the dosimeter's optical surface may have accumulated cannabis resin or other interferences during a shift, decreasing sensor response. However, contamination of the dosimeter by cannabis resin was minimized by placing the dosimeters on the back of the worker's neck where direct contact with the cannabis plants was minimized compared to if the dosimeter were placed on the worker's wrist.

Personal factors that may have affected UVR exposure measurements include tasks performed, body position and orientation concerning the light sources, use of PPE, and hair length. The tasks performed during a work shift influenced a worker's body position. For example, a worker may sit or crouch while pruning and stand while installing support nets. Body position influences proximity to the lamps and the body part orientation toward the optical source, both of which directly affect UVR exposure. Finally, long hair may have obstructed the neck-mounted dosimeters, reducing the measured UVR exposures.

Use of PPE such as long-sleeved clothing, hats, and sunglasses varied greatly by facility, ranging from shirtless to complete facial coverage via a ski mask. The PPE most commonly seen worn by the workers included hats, long-sleeved clothing, headscarves, and sunglasses. Workers at facility #4 where plants were primarily grown outdoors typically wore the greatest amount of PPE (hats, scarves, sunglasses, long-sleeved shirts, long trousers). The only worker-worn clothing that may have impacted our exposure measurements are wide-brimmed hats or baseball hats worn backward, as the hat brim had the potential to cast a shadow over the dosimeter. Workers wore a hat on 52% of work shifts. The mean UV exposure was 8.33×10^{-3} eff. J/cm^2 on work shifts where the workers wore a hat and 4.9×10^{-3} eff. J/cm^2 on work shifts where the workers did not wear a hat. This difference was statistically significant ($p = 0.031$) and may indicate that intense light conditions motivate a worker to opt to wear a hat. However, a paired t-test between the mean accumulated dose for hat wearers and non-hat wearers using only shifts with both groups represented ($n = 12$) did not show a significant difference between the two groups ($p = 0.57$). This suggests that the wearing of hats by the workers was unlikely to interfere with the UV measurements.

Conclusions

This study's primary finding is that a significant proportion of cannabis cultivation workers experienced UVR exposures that exceeded the ACGIH TLV, and hence the workers are potentially at risk of adverse effects of overexposure to UVR. It is reasonable to assume that many other agricultural workers with outdoor jobs are similarly overexposed to UVR. All of the overexposures observed were associated with solar radiation. However, several types of lamps used in cannabis facilities also emit UVR at levels high enough to cause exposures that exceed the ACGIH TLVs and the L&I PEL if workers were exposed for a long enough period. The risk of overexposure is greatly influenced by environmental and personal factors, including work location (indoors or outdoors), lamp type, and PPE use. Several of these risk factors are modifiable by employers and workers. Outdoor workers should employ sensible sun-safe practices including wearing hats, scarves, sunglasses, long-sleeved shirts, and long trousers, and application of sunscreen regularly to exposed skin. Employers should provide workers with appropriate training on the hazards of UVR and should provide workers with shade from the sun where possible. Employers should also choose low UVR emitting lamps (e.g., LED and fluorescent) for indoor grows and use engineering controls (e.g., door-interlocks to de-energize lamps) to prevent worker exposure to UVR from germicidal lamps. Additionally, given the high variability observed in UVR emissions within each lamp class, it may be helpful for lamp manufacturers to specify spectral density functions for lamps. This would allow consumers to readily choose low UVR-emitting lamps where appropriate.

This was a pilot study in a limited number of workplaces in a single state and thus may not be generalizable across the cannabis cultivation industry. As such, further research is needed to replicate the findings from this study and more fully understand the extent of UVR exposure and potential health hazards in this emerging industry. Additionally, grow lamp technology is advancing rapidly, with new lamp models released frequently. Newly introduced lamps to the market may produce high levels of UVR, and as such ongoing testing of UVR emissions may be needed. Finally, mismatches between a dosimeter's spectral response function and the ACGIH hazard function will cause bias in the dosimeter measurements of unknown magnitude and direction. Hence, exposure science would benefit greatly from the development of an inexpensive wearable spectroradiometer, or an inexpensive wearable dosimeter weighted to the ACGIH hazard function since such a device would provide the platform for future research and assist U.S. employers in identifying and protecting workers from the hazard of UVR exposure.

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Ethics approval

This study was reviewed and approved by the University of Washington Institutional Review Board (Study#: 00001805).

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Data availability statement

The data that support the findings of this study are available from the corresponding author, Max Chmielinski, upon reasonable request.

References

Allen M, McKenzie R. 2005. Enhanced UV exposure on a ski-field compared with exposures at sea level. Photochem Photobiol Sci. 4(5):429–437. doi:10.1039/b418942f.

American Conference of Governmental Industrial Hygienists (ACGIH). 2022. Ultraviolet radiation. Cincinnati, OH: ACGIH Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs).

Barcott B, Whitney B, Levenson MS, Kudialis C. 2022. Jobs Report 2022: Legal cannabis now supports 428,059 American jobs. Leafly. [accessed 2022 Dec 29]. https://www.leafly.com/news/industry/cannabis-jobs-report.

Borchardt D. 2017. Marijuana industry projected to create more jobs than manufacturing by 2020. Forbes. [accessed 2023 March 30]. https://www.forbes.com/sites/debra-borchardt/2017/02/22/marijuana-industry-projected-to-create-more-jobs-than-manufacturing-by-2020/?sh=29865ee93fa9.

Carliner H, Brown QL, Sarvet AL, Hasin DS. 2017. Cannabis use, attitudes, and legal status in the U.S.: a review. Prev Med. 104:13–23. doi:10.1016/j.ypmed.2017.07.008.

Caulkins JP, Bao Y, Davenport S, Fahli I, Guo Y, Kinnard K, Najewicz M, Renaud L, Kilmer B. 2018. Big data on a big new market: Insights from Washington State's legal cannabis market. Int J Drug Policy. 57:86–94. doi:10.1016/j.drugpo.2018.03.031.

Coblentz WW, Stair R, Hogue JM. 1931. The spectral erythemic reaction of the human skin to ultra-violet radiation. Proc Natl Acad Sci USA. 17(6):401–405. http://www.jstor.org/stable/86213. 10.1073/pnas.17.6.401

Green BJ, Couch JR, Lemons AR, Burton NC, Victory KR, Nayak AP, Beezhold DH. 2018. Microbial hazards during harvesting and processing at an outdoor United States cannabis farm. J Occup Environ Hyg. 15(5):430–440. doi:10.1080/15459624.2018.1432863.

Harris D. 2006. Quantitative chemical analysis. 7th ed. New York, NY: W. H. Freeman.

Hausser KW. 1928. Influence of wavelength in radiation biology. Strahlentherapie. 28:25–44.

Ichihashi M, Ueda M, Budiyanto A, Bito T, Oka M, Fukunaga M, Tsuru K, Horikawa T. 2003. UV-induced skin damage. Toxicology. 189(1–2):21–39. doi:10.1016/S0300-483X(03)00150-1.

International Agency for Research on Cancer (IARC). 2018. IARC monographs on the evaluation. Vol 35. Solar and Ultraviolet Radiation. Lyon: International Agency for Research on Cancer.

International Commission on Illumination (CIE). 1999. CIE S007/E-1998 Erythema reference action spectrum and standard erythema dose. Color Res Appl. 24(2):158. doi:10.1002/(SICI)1520-6378(199904)24:2<158::AID-COL11>3.0.CO;2-4.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). 2007. In collaboration with: International Labour Organization World Health Organization. Protecting Workers from UV Radiation. Munich: International Commission on Non-Ionizing Radiation Protection.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). 1997. Guidelines on limits of exposure to broad-band incoherent optical radiation (0.38 to 3 μm). Health Phys. 73(3):539–554.

Mahamad S, Hammond D. 2019. Retail price and availability of illicit cannabis in Canada. Addict Behav. 90:402–408. doi:10.1016/j.addbeh.2018.12.001.

Pitts DG, Cullen AP, Hacker PD. 1977. Ocular effects of ultraviolet radiation from 295 to 365 nm. Invest Ophthalmol Vis Sci. 16(10):932–939.

Pitts DG, Tredici TJ. 1971. The effects of ultraviolet on the eye. Am Ind Hyg Assoc J. 32(4):235–246. doi:10.1080/0002889718506444.

Scott C, Punja ZK. 2021. Evaluation of disease management approaches for powdery mildew on Cannabis sativa L.

(marijuana) plants. Can J Plant Pathol. 43(3):394–412. doi:10.1080/07060661.2020.1836026.

Seckmeyer G, Klingebiel M, Riechelmann S, Lohse I, McKenzie RL, Ben Liley J, Allen MW, Siani AM, Casale GR. 2012. A critical assessment of two types of personal UV dosimeters. Photochem Photobiol. 88(1):215–222. doi:10.1111/j.1751-1097.2011.01018.x.

Simpson C. 2017. Something old, something new. International Society of Exposure Science Newsletter. 3:11–14.

Sliney DH. 2001. Photoprotection of the eye-UV radiation and sunglasses. J Photochem Photobiol B. 64(2–3):166–175. doi:10.1016/s1011-1344(01)00229-9.

Solacure. 2016. Flower Power F40. [accessed 2022 May 23]. http://www.solacure.com/flowerpower.html.

Sperling A, Bergen T, Blattner P, Goodman T, Gugg-Helminger A, Sperfield P, Takeshita S. 2016. Characterization and calibration methods of UV radiometers. Vienna: International Commission on Illuminations. Vol. 220; p. 2016.

Surdu S, Fitzgerald EF, Bloom MS, Boscoe FP, Carpenter DO, Haase RF, Gurzau E, Rudnai P, Koppova K, Févotte J, et al. 2013. Occupational exposure to ultraviolet radiation and risk of non-melanoma skin cancer in a multinational European study. PLoS One. 8(4):e62359. doi:10.1371/journal.pone.0062359.

Washington State Administrative Code (WAC). 2003. Non-ionizing radiation WAC 296-62-09005. [accessed 2023 March 30]. https://app.leg.wa.gov/wac/default.aspx?cite=296-62-09005.

Washington State Auditor Office (WASAO). 2018. Marijuana producer process maps. [accessed 2023 March 30]. https://www.sao.wa.gov/wp-content/uploads/2018/11/ar1022033.pdf.

Washington State Department of Agriculture (WSDA). 2018. Pesticide and fertilizer use for the production of marijuana in Washington. [accessed 2023 March 30]. https://agr.wa.gov/departments/marijuana/pesticide-use.