HHE Health Hazard® Evaluation Program

Evaluation of Potential Hazards During Growing and Manufacture of Cannabis Products at an Indoor Cultivation and Retail Facility

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The Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 [29 USC 669a(6)]. The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations [42 CFR Part 85].

Availability of Report

Copies of this report have been sent to the employer and employees at the plant. The state and local health departments and the Occupational Safety and Health Administration Regional Office have also received a copy.

Recommended Citation

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Introduction

Request

Management at an indoor cannabis cultivation facility requested a health hazard evaluation of potential hazards associated with the harvesting, trimming, processing, and manufacturing of products for medicinal and recreational use. They were specifically concerned about exposures to dust, ozone, cannabis compounds, and microbial contaminants such as endotoxin and fungi. Management also asked for an evaluation of work practices that could lead to increased exposures.

Workplace

The main facility was a large single-story building with an adjacent retail area. The building contained grow rooms (greenhouses), a mother room for the original plant strains, harvesting and drying rooms, laboratory facilities for quality control and extraction, production areas, a waste processing area, and a separate loading dock. The waste processing and loading dock areas had elevated ceilings.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

The evaluation was designed to characterize potential exposures for employees working with cannabis plants and plant materials. We visited the facility in April and July 2019 and completed the following activities:

- Conducted confidential interviews about work and health concerns with employees who did cultivation, harvesting, trimming, and production activities.
- Observed work processes, work practices, and conditions.
- Measured employee and area exposures to endotoxins in air.
- Sampled surfaces for cannabinoids including delta-9 tetrahydrocannabinol (Δ9-THC), delta-9 tetrahydrocannabinol acid (Δ9-THCA), cannabidiol (CBD), and cannabinol (CBN).
- Identified fungi in personal and area air samples using gene sequencing.
- Measured sound levels for two machines in the production and laboratory areas of the facility.
- Measured area ozone concentrations in air.
- Measured area particulate concentrations in air during harvesting, trimming, and production activities.
- Measured area terpenes and other volatile organic compounds concentrations in air.
- Measured area carbon dioxide concentrations in air in the grow rooms.

Following each site visit, we provided a letter to facility management and employee representatives summarizing what we did and found during the site visit and initial recommendations.

To learn more about our methods, go to **Section B in the Supporting Technical Information**

Our Key Findings

Employees reported health symptoms that could be associated with potential exposures at work

- Employees reported eye, nose, and sinus symptoms, along with musculoskeletal symptoms, all of which improved when away from work.

Employees were exposed to particulates and endotoxins in the air, cannabinoids on surfaces, and noise from equipment

- When compared with other work areas, particulate levels were elevated at the pre-roll workstation and around the auto-batcher machine in the production areas.
- Endotoxin concentrations were below occupational exposure limits.
- Cannabinoids were found on work surfaces throughout the facility.
- Area noise measurements were elevated around the auto batcher machine in the production area and the sonicator in the laboratory.

Employees were exposed to highly repetitive work that increased their risk of musculoskeletal disorders

- Cultivation employees worked on their knees and often extended their arms long distances to maintain plants during the growing cycle.
- Harvesting and trimming employees were exposed to highly repetitive tasks while removing branches and leaves from the cannabis plants.
- Production employees spent long periods of time sitting at tables performing repetitive manual tasks.

To learn more about our results, go to **Section B in the Supporting Technical Information**

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Potential Benefits of Improving Workplace Health and Safety:

- Improved worker health and well-being
- Better workplace morale
- Easier employee recruiting and retention
- Enhanced image and reputation
- Superior products, processes, and services
- May increase overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or practical, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls at https://www.cdc.gov/niosh/hierarchy-of-controls/about/.

We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in *Recommended Practices for Safety and Health Programs* at https://www.osha.gov/safety-management.

Recommendation 1: Reduce exposures to particulates throughout the facility. Also provide respiratory protection for employees applying pesticides.

Why? Particulates, especially cannabis plant material, can contain endotoxins and allergens that have been associated with adverse respiratory health effects such as occupational asthma. The Environmental Protection Agency (EPA) registration for the pesticide used in the grow rooms required the use of respiratory protection.

We observed employees working with plant materials throughout the facility, especially in the grow rooms, and the harvesting, trimming, and production areas. Employees were dry sweeping floors throughout the facility. Sometimes compressed air was used to clean machines in the production area. Some employees voluntarily used dust or surgical masks. There was no respiratory protection policy for the pesticide application employee who was required to wear respiratory protection. Surgical or dust masks are not National Institute for Occupational Safety and Health (NIOSH) Approved® and are not designed to filter respirable particulates.

How? At your workplace, we recommend these specific actions:

Use wet methods or high-efficiency particulate air (HEPA) filter vacuums instead of dry sweeping or compressed air to clean.

- Train employees to use proper methods while cleaning. Wet methods (e.g., mops or surface wipes) and HEPA-filtered vacuums are preferred when cleaning up material left on the floors and work surfaces in the grow rooms, and the harvesting, trimming, and production areas.
- If using HEPA-filtered vacuums, consider respiratory protection for employees when they perform tasks like emptying the vacuum, changing filters, or other vacuum-related activities that might put dust back into the air.

Develop a written respiratory protection program for employees who are required to use respiratory protection. The program should include the elements that ensure that the respirator itself will not be a hazard for employees.

- The written program for using NIOSH Approved® N95® filtering facepiece respirators should include fit-testing, training, and medical evaluations of employees. The program should also include developing and implementing schedules for maintaining the respirators, including cleaning, disinfecting, storing, inspection, and repairing respirators. Additional details on what the program includes can be found in the Occupational Safety and Health Administration's (OSHA) Small Entity Compliance Guide for the Respiratory Protection Standard (osha.gov).
- Ensure that the respiratory protection program also complies with the EPA Agricultural Worker Protection Standard (WPS) | US EPA including when it is appropriate to use respiratory protection.

Continue to make NIOSH Approved N95 filtering facepiece respirators available in various sizes for those workers who voluntarily want to wear them.

- Provide voluntary N95 filtering facepiece respirator users with Appendix D of the OSHA Respiratory Protection Standard. Appendix D provides information for employees about using respirators when not required under the standard.
- Instruct employees who voluntarily wear respirators on how to wear them properly. NIOSH has publications for employees on how to wear filtering facepiece respirators such as disposable N95 respirators and other types of air-purifying respirators: How to Wear Your Filtering Facepiece Respirator (cdc.gov) and A Guide to Air-purifying Respirators, DHHS (NIOSH) Publication No. 2018-176 (cdc.gov).

Recommendation 2: Reduce exposures to cannabinoids in the workplace.

Why? Occupational exposures to cannabinoids are thought to occur by absorbing them through skin or by swallowing them. The long-term health effects of these occupational exposure routes are currently unknown. We expected to see cannabinoids in production areas but not in nonproduction areas. In this type of facility, cannabinoids found in nonproduction areas are likely brought out of the production areas on hands, shoes, clothing, and other items. Practicing good hand hygiene and cleaning practices in nonproduction areas is important to prevent unnecessary exposures.

We detected cannabinoids on production and nonproduction surfaces. We also observed employees drinking water at their workstations. Employees could be exposed to cannabinoids through dermal (skin) contact or hand-to-mouth actions (e.g., eating or drinking).

How? At your workplace, we recommend these specific actions:

Train employees about the importance of removing gloves and washing hands before using the bathroom, eating, drinking, or smoking.

- Instruct employees on proper handwashing techniques and when to wash their hands (e.g., before going on break, at the end of the workday, before using the restroom).
- Require that employees always remove gloves before leaving production areas.

Clean high-touch surfaces such as door handles as part of the daily cleaning schedule to reduce potential cannabinoids exposure.

Do not allow employees to eat or drink in production areas.

Recommendation 3: Encourage employees with work-related health concerns to talk to their supervisor or healthcare provider about their exposures to endotoxins, cannabinoids, particulates and musculoskeletal issues.

Why? Identifying symptoms early can reduce their severity and lead to the correct management and treatment if needed. Recognizing work-related symptoms early can also help identify potential occupational exposures and risk factors for disease. It can also help prioritize actions to prevent employees from developing diseases.

Work-related symptoms are symptoms that typically improve on days away from work or on vacation. An individualized management plan (such as assigning an affected employee to a different work location like home or a remote site) is sometimes required, depending upon medical findings and recommendations of the individual's healthcare provider.

How? At your workplace, we recommend these specific actions:

Encourage employees to report any symptoms they believe are work-related to their supervisor.

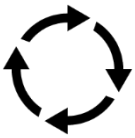
- Supervisors should refer employees to an occupational health physician or their primary care provider to discuss their individual health concerns and questions about work-related symptoms
- If needed, employees can seek care for work-related medical concerns from a healthcare provider knowledgeable in occupational medicine.
    - The American College of Occupational and Environmental Medicine (https://acoem.org/Find-a-Provider) and the Association of Occupational and Environmental Clinics (https://aoec.org/members/) maintain databases of providers to help locate someone in your geographic area.
    - Tell employees to consider sharing this report with their healthcare provider.

Recommendation 4: Reduce risks for musculoskeletal disorders.

Why? Musculoskeletal disorders are conditions that involve the nerves, tendons, muscles, and supporting structures of the body. They can cause chronic pain and limited movement. A substantial body of data shows strong evidence of an association between musculoskeletal disorders and certain work-related factors, including physical, work organizational, and psychosocial. The preferred way to prevent and control work-related musculoskeletal disorders is to design tasks, workstations, tools, and other equipment to match the physical and mental characteristics of employees.

We observed employees doing highly repetitive work during cultivation, hand trimming, harvesting plants, and other production activities. These activities increase their risk of musculoskeletal disorders. Cultivation employees had to kneel to reach the bottom trays of plants and had to reach into the growing trays to maintain the plants. Harvesting employees experienced repetitive work with frequent bending and reaching to access plastic trellis netting and stems on the lower parts of the plants. Trimming employees used trimming scissors or hand-stripping to remove leaves from the branches. Production employees spent long periods sitting at tables performing their manual tasks that included weighing, closing containers, and attaching individual labels.

How? At your workplace, we recommend these specific actions:



Rotate job tasks for employees performing highly repetitive work.

- Develop a job rotation plan to move employees working in frequent hand-and-finger-movement tasks to other jobs that require using different muscle-tendon groups. An effective job rotation plan will reduce the risk of musculoskeletal disorders.
- Provide frequent breaks for employees who use their hands and fingers repetitively, such as production and hand trimming.

Provide employees with clean, sharp tools.

- Discuss equipment needs with trimming employees regularly and replace or maintain cutting tools as needed.

Provide plant care employees with knee pads, garden kneeling pads, or mats.

- Discuss with plant care employees what equipment they would prefer to use to reduce stress on the knees.

Consider hiring a consultant to conduct ergonomic assessments for the jobs that require highly repetitive work.

Recommendation 5: Reduce potential exposures to noise in the workplace.

Why? Noise-induced hearing loss is an irreversible condition that gets worse with noise exposure. Unlike some other types of hearing disorders, noise-induced hearing loss has no cure and cannot be treated medically. Noise-exposed workers can develop substantial noise-induced hearing loss before it is recognized.

We measured area noise levels near the auto batcher machine in the production area and the sonicator in the laboratory. Both were above occupational exposure action levels.

How? At your workplace, we recommend these specific actions:

Conduct a full-shift personal noise survey to determine if employees are exposed to noises above NIOSH or OSHA noise exposure action levels. If so, a hearing loss prevention program would be needed.

- More information on establishing a hearing loss prevention program can be found at https://www.osha.gov/noise/hearing-programs.

Offer hearing protection to employees.

- Train employees on how to correctly use the hearing protection provided (e.g., earplugs, earmuffs).
- Ensure that enough supplies of hearing protection are available for employees to use.

Recommendation 6: Address other health and safety issues we identified during our evaluation.

Why? A workplace can have multiple health hazards that cause worker illness or injury. Similar to the ones identified above, these hazards can potentially cause serious health symptoms, lower morale, and impact the quality of life for your employees, and possibly increased costs to your business. We saw the following potential issues at your workplace:

- Three grow rooms lacked baseboards. This left drywall exposed to water on a regular basis, which could lead to mold growth.
- Branches could potentially poke harvesters in the eye while they worked in the grow room.
- Portable squirt bottles were in the laboratory to serve as an eye wash station.
- The compressed air cylinder in the laboratory was not chained.
- No fire extinguishers were located in the laboratory.
- Compressed air cylinders and wooden pallets were stored beside and in front of the flammable storage cabinet in the loading dock.
- A high bay area in the waste disposal area did not have any fall protection railings.

Although they were not the focus of our evaluation, these hazards could cause harm to your workers' health and safety and should be addressed.

How? At your workplace, we recommend these specific actions:

Install baseboard along the grow room walls, as in the other grow rooms, to prevent mold growth on the drywall.

- Information about remediating mold-damaged building materials is available in the U.S. Environmental Protection Agency (EPA) document titled Mold Remediation in Schools and Commercial Buildings (EPA 402-K-01-001, September 2008).

Provide safety glasses or safety sunglasses to prevent eye injury from plant branches during harvesting.

Install a plumbed eye wash station in the laboratory.

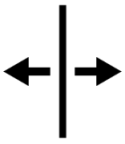
- Ensure that eye wash stations and emergency showers are accessible, provide adequate flow of tepid water, and avoid blockage by equipment.

Secure the compressed air cylinder in the laboratory.

- The compressed air cylinder must be secured upright with a chain or strap so it will not tip over. The cylinder must have a valve protection cap in place when not in use.

Install pressurized dry chemical (Type BC or ABC) or carbon dioxide fire extinguishers in the laboratory due to the presence of solvents.

- Additional health and safety guidelines for the laboratory can be found in the OSHA Booklet: Laboratory Safety Guidance.



Remove the compressed air cylinders and wooden pallets from in front of the flammable liquid storage cabinet in the loading dock.

- Moving the items away from the cabinet would reduce potential fuel and other hazards in case of fire.

Install a railing in the high bay of the waste disposal area to prevent falls.

Supporting Technical Information

Evaluation of Potential Hazards During Growing and Manufacture of Cannabis Products at an Indoor Cultivation and Retail Facility

HHE Report No. 2019-0107-3412

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Section A: Workplace Information

Building

The main facility was a single building that housed production areas with an adjacent retail facility. The waste processing area and loading dock had elevated ceilings. This facility cultivated, harvested, trimmed, packaged, and prepared cannabis products for sale in the retail facility. The retail facility was not part of the health hazard evaluation request.

The main building area was serviced by a large heating, ventilating, and air-conditioning (HVAC) system. The HVAC system had an open-air plenum above ceiling tiles. The returns had dampers to control flow into the recirculating system. The HVAC system maintenance was contracted out to a service provider. At the time of the site visit, the air filters in the main unit had a minimum efficiency reporting value (MERV) 8 rating.

Employee Information

Employees were full-time, working a single 8-hour shift over a 5-day work week. Seventy-three employees worked at the facility at the time of the site visits. Managers and team leaders worked full-time, occasionally working longer workdays depending on the production schedule. The facility was not unionized at the time of the NIOSH site visit.

Process and Employee Task Descriptions

Cultivation

Cultivation began in the mother room (clone room) where employees removed cuttings from mature donor plants. The cuttings grew into new individual plants (clones) that were genetically the same as the mother plants. As the cuttings developed roots, cultivation employees planted them in small containers. After about two weeks, employees transplanted the cuttings into larger containers and moved them into one of seven grow rooms. Employees arranged the same species of plants in plastic trays in double tiers in several rows. Employees used movable stairs or scaffolds to reach the second tier.

Employees tended to the plants, which included watering with ozone-treated water and adding fertilizer and nematodes to control gnats (Figure A1). They removed lower leaves weekly, either by hand or with shears, to promote plant growth. This involved reaching in and around the plants. When the plants reached certain heights, employees attached plastic mesh to the plastic trays to support plant growth. Employees harvested the plants when they reached maturity.

Mechanical ventilation was provided for each grow room. Carbon dioxide (CO_2) was added to the grow room atmosphere at a concentration of 100 parts per million (ppm) to promote plant growth. The grow rooms had direct-reading CO_2 monitoring mounted on the walls. Employees used a shop vacuum or dry swept to clean up plant materials. They wet mopped the floors at least weekly.

Figure A1. Employee watering lower tier of plants in grow room. Photo by NIOSH.

Harvesting

After the plants reached maturity, employees harvested them in the grow rooms. Employees removed the plastic netting supporting the plants. The harvesters cut the large branches containing the cannabis flowers and placed them in totes for transport. This required highly repetitive motions. After harvesting was complete, employees cleaned the grow room to prepare for a new set of plants. One employee was responsible for pesticide and fungicide applications (ZeroTol® 2.0, BioSafe Systems, East Hartford, Connecticut). A carbon-filter air cleaner was used in the grow room after the effective treatment time for the fungicide application to remove any residual pesticide before employees reentered.

Trimming (Bucking Room)

Employees sat on stools and removed the flower buds and leaves (the process is called bucking) from the plant stems with trim scissors or by hand-stripping. They placed flower buds on branches in trays and discarded the leaves (Figure A2). These employees worked in production when not involved with trimming. There was a stand-alone air cleaner with a high-efficiency filter in the corner of the room. The main building ventilation system supply and return grilles were sealed so that any airborne contaminants that were generated did not enter the rest of the building.

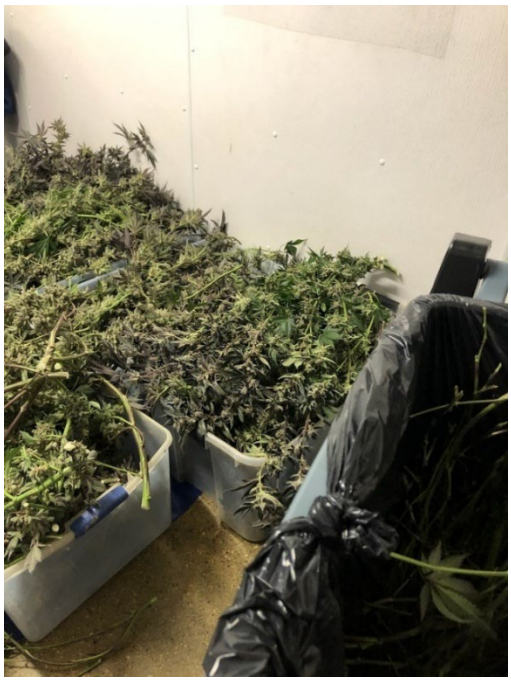

Figure A2. After harvesting, flower buds are placed in plastic totes before the buds are hung on racks for the drying process. Photo by NIOSH.

Drying

After trimming, employees transferred the trays with the branches to the drying rooms (Rooms B and C). The hanger placed the branches on racks where they cured for 2 to 4 weeks before going to laboratory testing. Drying room ventilation was blocked off from the general HVAC system to prevent airborne contaminants from entering other areas. The company used a dry trimming machine for bud removal.

Laboratory Processing

Employees were responsible for running the decarboxylation process. During this process, raw cannabis was heated using a convention oven to activate the cannabinoids. An automated system used CO_2 gas to extract essential oils. This activated the ingredients from the plant material while keeping the plant terpenes. Employees also used an automated CO_2 distillation process to refine the essential oil extract to create a flavorless, tasteless oil. Workers then used a sonicator as an additional extraction process. The laboratory employees were in charge of product concentration measurements, which included determining the dosage and terpene analyses for the various products.

The extraction area was separate from the rest of the building. It had its own HVAC system with an explosive-proof exhaust fan that vented directly to the outside of the building.

Production

Employees were cross-trained for other job tasks throughout the production areas, working in harvesting and trimming when needed.

Pre-roll Room

Employees took the dried cannabis product to the pre-roll room (Room A). A grinding machine in the room ground the flower buds into the appropriate size. The grinding machine was usually run when no employees were in the room because it was a dusty operation. There were two free-standing high-efficiency particulate air (HEPA) filtration units in the surrounding area near the grinding machine to capture dust. The ground material was then taken to the packaging area (Figure A3). The company used a knock-out box for filling and packing 100 rolls at a time. Employees took each roll, weighed it twice, and put it into a container. They then sealed and labeled each container and placed it into a storage bin.

Figure A3. Pre-roll workstation showing the knock-out boxes, containers, and labeling equipment. A DustTrak® is shown in the background, which measures aerosols generated during the work tasks. Photo by NIOSH.

Production Room

The production room had cartridge, capsule, lotion, and tincture filling machines that used tetrahydrocannabinol (THC) distillate oil. The products included capsules filled with infused coconut oil and tinctures filled with infused grape seed oil. THC distillate oil from the laboratory was also packaged in different-size reusable cartridges and disposable vape pens.

One of the production machines (auto batcher) automatically double-weighed flower buds into retail containers. An employee sealed and labeled the containers. Another weighing machine was run by an operator who added and weighed flower buds on a scale, which were then placed in retail containers.

Several of the production jobs included closing and capping retail containers after filling or heat-sealing clam shells. All products required sticking on labels by hand. Employees switched workstations daily, but the hand tasks were similar between jobs. They had adjustable wheeled chairs and mats.

Kitchen

The facility had a fully staffed kitchen under the supervision of a chef. The employees took THC distillate oil from the laboratory and incorporated it into the recipes. They produced cookies, gummies, hard candy, caramels, brownies, mini-drinks, and other consumables for sale in the adjacent retail store.

Cleaning and Waste Handling

Management required employees to routinely sanitize their work areas at the beginning and end of the workday. Occasionally, employees used compressed air for cleaning in the production area near the weighing stations. Employees did a deep clean every Friday to remove any additional plant materials. All plant waste created during the growing and production process was weighed and taken to the waste disposal area. There it was added to regular waste, ground together to make it unfit for consumption, and sent to a regulated landfill.

Section B: Methods, Results, and Discussion

Methods: Employee Interviews

All employees who were working in April 2019 were invited to participate in interviews. Employees from each area participated. Eight employees from production, four from cultivation, and four from the kitchen participated in the interviews. At the start of each interview, we reminded the employee that participating in the interview was voluntary and confidential.

Results: Employee Interviews

We interviewed 16 (59%) of 27 employees available for interviews at the time of the first site visit. The maximum possible tenure was 18 months. The median tenure among the 16 employees we interviewed was 4 months (range: <1 month–18 months). The median hours worked per week was 41 (range: 35–48 hours). The most common health symptoms reported were eye, nose, or sinus symptoms (12 [75%]) and musculoskeletal symptoms (9 [56%]). Dermal issues were not reported. Of the 12 participants who reported eye, nose, or sinus symptoms, 10 reported that tasks at work caused the irritation, with six reporting that they worked in the production area. Of the 12, 5 reported that eye, nose, or sinus symptoms improved when away from work on their days off or on vacation.

One employee reported work-related breathing problems such as coughing, shortness of breath, chest tightness, or wheezing. The most frequently reported body parts affected by musculoskeletal symptoms were back (6), shoulder (2), and wrist pain (2), with one employee reporting issues with two body parts. Of the nine employees who reported musculoskeletal symptoms five reported that tasks at work caused or exacerbated the problems.

Methods: Observations of Work Processes, Practices, and Conditions

During our two visits to the facility, we observed the work processes and practices, workplace conditions of employees, and personal protective equipment usage as they performed cultivating, harvesting, drying, trimming, and production tasks.

Results: Observations of Work Processes, Practices, and Conditions

Observations

We noted that employees in the grow rooms were kneeling on the concrete floor working with the plants. During harvesting in the grow room, we saw a potential for eye injury from the plant branches. We also noticed exposed drywall at the bottom of the walls in three of the grow rooms. This could lead to mold growth from water exposure and high relative humidity levels.

In the laboratory, portable squirt bottles were available to serve as an eye wash station, but we observed no permanent fixtures. The CO_2 compressed air cylinder tank was not restrained by a chain or stand to prevent it from falling over. If the tank were to fall and break off the safety valve, it could become a projectile. We also observed compressed air cylinders and wooden pallets stored beside and in front of the flammable storage cabinet in the loading dock. This could pose a safety risk. The high bay of the waste disposal area did not have a railing to serve as fall protection.

We observed workers with open drinks on the shelves under their workstations. Throughout the workday, we noted a build-up of plant material on the pre-roll workstation.

Personal Protective Equipment

We observed some employees using surgical or dust masks in the cultivation, trimming (bucking) room, pre-roll, and production areas. These devices were not NIOSH approved for respiratory protection. In addition, we observed some employees using NIOSH Approved N95 filtering facepiece respirators in the laboratory. The company provided the masks and N95 respirators to employees for voluntary use. We observed the pesticide applicator using a full-facepiece elastomeric air-purifying respirator equipped with organic vapor cartridges; however, the company did not have a written respiratory protection program at the time of the site visits.

Company uniforms (scrubs) were required for all jobs throughout the facility. Employees changed into scrubs when entering the grow facility, changing back into street clothes at the end of their shift. The company used a uniform service to launder the scrubs. Hair and beard nets and nitrile gloves were used in the pre-roll, laboratory, and production areas. Rubber gloves were used during cultivation and harvesting. Sleeve covers were available for employees to use if desired; several employees used them in the grow and bucking rooms and during harvesting. Employees were responsible for laundering their own sleeve covers.

Employees in the grow rooms wore safety sunglasses and baseball caps. Booties were required to enter the work areas. Employees were required to spray feet with isopropyl alcohol when entering rooms. Employees in the laboratory were also required to wear laboratory coats while in the laboratory and anti-static wrist bands and safety glasses for some laboratory procedures. Trash bins were available in the work areas to dispose of single-use personal protective equipment.

Methods: Exposure Assessment

Endotoxins

In July 2019, we collected personal and area air samples on cultivation and harvesting employees using three-piece, 37-millimeter-diameter closed-faced cassettes with 0.45-micrometer (µm) pore size preloaded polycarbonate filters. The sampling pumps were calibrated at a flow rate of 2 liters of air per minute. Each sample was analyzed for endotoxin using an Endpoint Chromogenic Limulus Amebocyte Lysate Assay [Thorne et al. 2010]. The assay was a quantitative test used to detect Gram-negative bacterial endotoxin. We collected personal air samples for endotoxin on six different production employees over 2 days during their entire work shift (three employees per day). We paused samples and removed pumps from employees during breaks. We also collected six area air samples in different parts of the production area. For these analyses, the limit of detection was 0.31 endotoxin units (EU) per sample.

Cannabinoids

In July 2019, we collected surface wipe samples in production areas of the facility and analyzed for Δ9-THC, Δ9-THCA, CBD, and CBN. Where possible, we collected two samples (one for Δ9-THC and a second for all four cannabinoids) in each location. The two samples were taken directly adjacent to one another whenever possible. Each sample was collected with a cotton twill wipe moistened with

3 milliliters (mL) of isopropanol. All samples were collected using a disposable 100-square-centimeter (100 cm^2) template. If the template was not feasible (e.g., the surface was an irregular shape, such as a door handle, that did not lend itself to using the template), approximately 100 cm^2 of surface was wiped for the sample.

Each pair of samples were analyzed using two methods, one for each sample. One sample was analyzed for Δ9-THC using a contract laboratory's internal method. This method used high performance liquid chromatography and tandem mass spectrometry with a limit of detection of 8 nanograms per sample. The second sample was analyzed for Δ9-THC, Δ9-THCA, CBD, and CBN using a modified method [Ambach et al. 2014]. The modified method used high performance liquid chromatography with diode-array detection with a limit of detection of 2 micrograms (µg) per sample for Δ9-THC and 3 µg per sample for the other three analytes.

Identification of Fungi in Air Samples

Genomic DNA Extraction from Air Samples

In July 2019, we collected personal breathing zone air samples (n = 5) and general area air samples (n = 10) using the NIOSH BC251 two-stage air sampler in conjunction with a sampling pump. The sampling pumps were calibrated at a flow rate of 2 liters of air per minute. Air samples were processed for fungal DNA extraction using the Roche High Pure Polymerase Chain Reaction (PCR) Template kit as previously described [Green et al. 2017; Green et al. 2018]. Each stage from the NIOSH BC251 air sampler was combined. Afterward, the filter was sectioned into six pieces with a scalpel and aseptic methods. These pieces were placed into a 2-mL bead-beater tube containing 300 µg of glass beads. The tubes were placed in liquid nitrogen for 30 seconds and processed in a bead mill homogenizer for 30 seconds. This process was repeated one more time.

The High Pure PCR Template kit lysis buffer (650 microliters [µL]) was then sequentially added to the first and second stage tubes and vortexed to collect the sampled materials. The lysis buffer was added to the 2 mL tube containing the macerated filter material. We processed the tubes with a bead mill homogenizer for 30 seconds and then centrifuged for 1 minute at 20,000 × *g*, a measure of relative centrifugal force. We collected the supernatant and incubated with 40 µL Cell Lytic B lysis reagent (Sigma Aldrich) for 15 minutes at 37°C. We mixed the sample with the kit's binding buffer (200 µL) and proteinase K (40 µL) and then incubated at 70°C for 10 minutes. We washed the sample and eluted the DNA in 100 µL of isopropanol as recommended by the manufacturer.

Fungal ITS Region Amplification, Cloning, and Sanger Sequencing

We amplified the fungal Internal Transcribed Spacer (ITS) regions using a procedure modified from that which was previously described [Green et al. 2017; Green et al. 2018]. Briefly, the fungal ITS1 region sequences were amplified with the primer pair ITS1F (CTTGGTCATTTAGAGGAAGTAA) and ITS2aR (GCTGCGTTCTTCATCGATGC) using Platinum Taq DNA polymerase (Invitrogen). For fungal amplification, three replicate PCR reactions (50 µL) were run for each sample by using 5 µL of DNA template. These replicates were then combined, and the rDNA amplicons were purified with a Qiagen PCR purification kit, according to the manufacturer's instructions.

We separately cloned fungal amplicons into the pDRIVE vector using a Qiagen PCR cloning kit. We generated clone libraries by transforming cloned plasmids into chemically competent *Escherichia coli* cells

as previously described [Green et al. 2017]. We selected 24 positive colonies per air sample (as determined colorimetrically by the inactivation of the lacZ gene). We then cultured the colonies for 16 hours at 37°C in liquid Luria-Bertani media containing 100 µg/mL of ampicillin. Resultant cells were centrifuged at 1800 × *g* (relative centrifugal force) and the pellet resuspended in 200 µL of 15% glycerol. The cells were sent for Sanger sequencing of the fungal ITS1 insert from Genewiz, Inc. Inserts were sequenced in both directions, allowing for sequence analysis of the full ITS1 region.

Sequencing results were downloaded as ".ab1" trace files from Genewiz Inc. Vector sequence data were trimmed and forward and reverse sequences were assembled using Biomatters Geneious R7 Software. Sequence data were then clustered into operational taxonomic units with MOTHUR software version 1.32.1 using a 97% similarity cutoff as described in previous publications [Green et al. 2017]. Sequences representative of each operational taxonomic unit was then used in a Basic Local Alignment Search Tool search against the National Center for Biotechnology Information database.

Noise

In April 2019, we measured area noise levels near the auto batcher machine in the production area and the laboratory sonicator while the machines were operating. We used a Quest™ 3M Model 2400 calibrated, battery-operated, type-2 sound level meter (3M, Maplewood, Minnesota).

Ozone

In April 2019, we measured ozone concentrations in the air using direct-reading Draeger® colorimetric indicator tubes (Draeger Safety, Inc., Pittsburgh, Pennsylvania) in the cultivation area of the facility. The Draeger tubes had a limit of detection of 0.05 ppm.

Particulates

In July 2019, we measured particulates in four areas of the facility for a full shift using DustTrak™ DRX 8533 Aerosol Monitors (TSI, Inc., Shoreview, Minnesota). We had previously measured particulate levels in the pre-roll area in April 2019. Two monitors were in the pre-roll area and the auto-batcher on July 9, 2019, and three monitors were set-up in Flower Room 3, the Bucking Room C, and the auto batcher on July 10, 2019. All monitors were set to log particle concentrations every 60 seconds in different size groups: particulate matter (PM) smaller than 1 µm (PM1), PM smaller than 2.5 µm (PM2.5), respirable (less than 4 µm), PM smaller than 10 µm (PM10), and total PM (less than 100 µm).

Volatile Organic Compounds and Terpenes

In July 2019, we collected seven area air samples using thermal desorption tubes to identify volatile contaminants at the facility. These tubes were analyzed by gas chromatography/mass spectrometry using NIOSH Method 2549 [NIOSH 2024]. We also collected seven area air samples using charcoal tubes at 0.1 liters per minute in the same locations as the thermal desorption tubes. These samples were analyzed for 21 different terpenes (one of the main groups of VOCs identified from the thermal tube analyses). Terpenes have a strong odor and give cannabis its characteristic smell. The samples were analyzed by gas chromatography/mass spectrometry using NIOSH Method 1552 [NIOSH 2024].

Carbon Dioxide

In April 2019, we collected area CO_2 measurements using a TSI® Q-Trak in seven grow rooms and the mother room.

Results: Exposure Assessment

Endotoxins

Endotoxins were detected in all personal air samples collected in the production areas (Table C1). Exposures from personal air samples ranged from 1.4–27.6 endotoxin units per cubic meter of air (EU/m^3). None of the employees were exposed to endotoxins above the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®) limit of 90 EU/m^3 [ACGIH 2024]. Area measurements ranged from not detected–12.7 EU/m^3 (Table C2).

Cannabinoids

We collected surface wipe samples for cannabinoids using two methods in 22 locations throughout the facility (Table C3). One method analyzed samples for Δ9-THC only. The second method analyzed samples for multiple cannabinoids simultaneously (Δ9-THC, Δ9-THCA, CBD, and CBN). For the Δ9-THC only method, all surface wipe samples had detectable levels of Δ9-THC. The Δ9-THC surface wipe results ranged 0.19–330 µg/100 cm^2.

For the method analyzing samples for multiple cannabinoids simultaneously, 10 of 18 surface wipe samples had detectable levels of Δ9-THC (range: not detected–140 µg/100 cm^2). Δ9-THCA was detected in 17 of the 18 samples (range: not detected–530 µg/100 cm^2). CBD and CBN were detected but not at quantifiable concentrations on the cartridge workstation, the batcher by the scales, and the drying rack in Bucking Room C.

Identification of Fungi in Air Samples

Molecular analysis of personal breathing zone (n = 5), general area air samples (n = 10), and field blanks (n = 2), revealed only 131 fungal DNA sequences derived from 42 fungal species. Based on the low number of fungal sequences that resulted from these analyses, it was assumed that the fungal DNA yield within these samples was extremely low. Table C4 shows the most abundant species identified in the area and personal breathing zone air samples. The most sequenced fungus in both area and personal samples was identified as *Pseudopithomyces chartarum*; a species that is taxonomically placed in the Ascomycota order Pleosporales. This fungus made up 20% and 33% of all fungal sequences identified in area and personal breathing zone samples, respectively. This fungal species is typically isolated from the phyllosphere and is common on plant leaves and stems. Other fungi identified belonged to the genera *Aspergillus* and *Penicillium*, which are ubiquitous in the air and can be associated with moldy foods and damp environments. Another commonly encountered fungal species was *Malassezia globosa*, a yeast typically associated with the skin and a common cause of dandruff.

Noise

Sound levels measured near the auto batcher machine while compressed air was used ranged 81 to 97 decibels A-weighted (dBA). Sound levels near the sonicator were 89 to 95 dBA. The measurements cannot be directly compared with occupational exposure limits (OELs) since they are not personal exposure measurements collected as full-shift time-weighted averages. However, at a sound level of 90 dBA, employees' full-shift noise exposures would be above the NIOSH recommended exposure limit (REL) in 2.5 hours, above the OSHA permissible exposure limit (PEL) in 8 hours, and above the

OSHA action level (AL) in 4 hours. Some employees were wearing ear plugs in the production areas, but it was not required.

Ozone

The results of the air sampling for ozone are shown in Table C5. We detected ozone at the top of the water tank at 0.1 ppm, but ozone was not detectable in the other locations sampled.

Particulates

The particle mass concentration data from the direct reading instruments are presented in Table C6. The highest respirable dust measurements were found in the pre-roll work area in April 2019 (average: 0.018; range: 0.002–6.55 milligrams per cubic meter of air [mg/m^3]). Average respirable particle mass concentrations were low in all five areas in July 2019. The respirable dust measurements in July 2019 ranged 0.002–0.969 mg/m^3 in the pre-roll area; 0.006–1.14 mg/m^3 in the auto batcher area; 0.004–0.073 mg/m^3 in the Grow Room 3 area; 0.003–0.075 mg/m^3 in the Bucking Room C area; and 0.005–0.153 mg/m^3 in the auto batcher area.

Volatile Organic Compounds and Terpenes

During the July 2019 site visit, we collected thermal desorption tube samples throughout the production area to screen for volatile organic compounds (VOCs) associated with working with cannabis. The most prevalent VOCs identified included ethanol, isopropanol, and a variety of C10H16 terpenes, primarily alpha-pinene, beta-pinene and limonene. Other compounds identified include acetaldehyde, propene, acetone, ethyl acetate, ethyl dimethylacrylate, cymene, linalool, decamethylcyclopentasiloxane, caryophyllene, and other C15H24 terpenes.

The terpene results of the area air sample analyses are shown in Table C7. The five most detected terpenes were alpha-pinene (range: 10–140 parts per billion [ppb]; beta-myrcene (range: 42–1,340 ppb); beta-pinene (range: 6–170 ppb); limonene (range: 68–2,170 ppb); and linalool (range: 1–100 ppb). There are no OELs for terpenes in area air samples.

Carbon Dioxide

The results for the area air samples for the grow and clone rooms are presented in Table C8. The CO_2 levels ranged 1,250–1,890 ppm in the grow rooms and 520–780 ppm in the clone room. There are no OELs for area CO_2 measurements; however, OSHA has an 8-hour time-weighted average PEL of 5,000 ppm.

Discussion

The confidential medical interview results provided a "snapshot" of employee health concerns during our first site visit. The interviews' results determined that some of the employees reported eye, nose, or sinus symptoms and musculoskeletal symptoms they associated with the workplace. The reported allergic and respiratory symptoms could potentially be related to cannabis compounds and/or fungal exposures

The National Academies of Sciences, Engineering, and Medicine have found that cannabis industry employees have exposures similar to other agricultural employees including exposures to respiratory irritants and ergonomic injuries [National Academies of Sciences, Engineering, and Medicine 2024].

Many studies have linked employment in the cannabis industry with respiratory problems including occupational asthma and allergies [Beckman et al. 2022; Decuyper et al. 2020; Eidem et al. 2024; Sack et al. 2023; Weaver et al. 2023]. Many of the tasks we observed in the grow rooms, and harvesting, trimming, and production areas required repetitive motions and awkward postures. It is important management communicate and receive input about work and well-being from employees on a regular basis. This will help employees and employers work together to design work and employment conditions to prioritize health and safety.

These reported health issues, work practice observations, and additional scientific evidence of respiratory and dermal issues among cannabis employees [Beckman et al. 2022; Couch et al. 2020] led to our recommendations to reduce exposures. Information on workplace exposures and health effects can be found at Workplace Safety and Health Hazards | Cannabis | CDC and Cannabis Health Effects | Cannabis and Public Health | CDC. Additional information on policies, programs, and practices that combine protection from work-related safety and health hazards with the promotion of injury and illness-prevention efforts is part of the NIOSH Total Worker Health™ program. This integrated strategy is designed to advance worker well-being and can be found throughout the program at *Total Worker Health*® | Total Worker Health | CDC.

Exposures to airborne endotoxins come from soil- and plant-disturbing activities. During our evaluation, we observed employees taking care of plants in the grow rooms, harvesting plants (e.g., cutting branches, trimming off leaves), working with plant materials in the production areas, and dry sweeping in the grow rooms. These activities increased the opportunity for exposure to airborne endotoxin. The airborne exposures we found were similar to those detected in other cannabis facilities. The personal airborne endotoxin levels found at previously evaluated facilities include an outdoor cannabis farm (range: 3–37 EU/m^3), an indoor and outdoor cannabis cultivation facility (range: 1–85 EU/m^3), and an indoor cultivation facility (range: 6–980 EU/m^3) [NIOSH 2017, 2019a, 2022].

The main way cannabinoids are distinguished is by the degree of their psychoactivity, which evaluates how a person's nervous system is affected by the compound. Δ9-THC is the psychoactive component of cannabis, whereas Δ9-THCA, CBD, and CBN are not psychoactive substances. The long-term health effects of occupational exposures to these cannabinoids have not been determined. The differences between occupational exposures to psychoactive cannabinoids and non-psychoactive cannabinoids are also unknown.

We detected cannabinoids on both cultivation and production surfaces, although in general, the cultivation surfaces had lower concentrations compared to the production surfaces. Cannabinoids are expected to be found in these areas. While collecting surface wipe samples, efforts were made to ensure that most samples were adjacent to each other. However, because of presumed unequal distribution of cannabinoids across surfaces, even when directly adjacent, we cannot directly compare results between the two methods. The detected concentrations are consistent with other evaluations in similar workplaces [Couch et al. 2020; NIOSH 2019a, 2022].

The most abundant fungal species detected in the personal and area air samples was *Pseudopithomyces chartarum*. *P. chartarum* is a plant fungus commonly found in soil, on dead leaves, and on *Cannabis sativa* plants [Ponnappa 1977]. Human health effects, if any, attributable to *P. chartarum* exposure, are

unknown. The fungus has been reported to cause facial eczema in sheep [McRae et al. 2021]. *Penicillium chrysogenum* and *Malassezia globosa* were also detected in the area air samples. *P. chrysogenum* is found in soil and vegetation. It can cause opportunistic infections, especially among immuno-compromised individuals. *M. globosa* is a yeast-like fungus that is a normal component of human skin. It has been associated with dandruff and dermatitis. *Aspergillus tamarii* and *Penicillium citrinum* were detected in the personal air samples. Both are found in soil. *P. citrinum* is used to make an anticholesterolemic drug for human consumption [Houbraken et al. 2010; Punja et al. 2019].

Area noise measurements indicated that, at times, the sound levels we measured reached levels over the NIOSH REL and OSHA AL of 85 dBA, indicating a potential for overexposure to noise. We found that noise levels were greater near the auto batcher machine in the production area and the sonicator in the laboratory. The measurements we collected were short-term area measurements and could not accurately capture individual exposures. These indicated a need for an additional noise survey for employees in those work areas.

Ozone was added to the water to help plant growth. We were only able to detect low levels of ozone in the sprinkler room where it was directly added to the water system. Ozone has a low odor threshold, so it was possible that employees could detect the chemical at levels that were not able to be measured. Exposure to low concentrations of ozone may cause headaches and skin and respiratory irritation [NIOSH 2019b].

Our results from particulate monitoring indicate that dust exposures were highest in the production areas for the pre-roll workstation and near the auto-batcher, which uses compressed air. There are no specific OELs that can be used to evaluate these exposures since these dusts contain known allergens. Individual reactions to allergens can vary from none to severe which is why no exposure limits have been established. There are OELs for general dust that are known to not contain harmful components. Additionally, area samples cannot be compared to OELs since OELs are based on personal exposure levels. In this evaluation, we sampled areas where we expected work processes may yield particulates, and we were able to confirm that this was the case. The particulates generated in these areas are likely to be plant material that contain endotoxins and cannabinoids.

Terpenes are a class of VOCs with strong odors and give cannabis strains their characteristic smells and flavors [Sommano et al. 2020]. Although low levels of terpenes are not associated with adverse health effects, terpenes can be absorbed through the skin and gastrointestinal tract [Davidson et al. 2018; Silvey et al. 2020]. The most commonly detected compounds in our evaluation were similar to those found in other studies [Silvey et al. 2020; Sommano et al. 2020; Urso et al. 2023]. The highest concentrations were found where cannabis plant material was being handled. There are no specific OELs that can be used to evaluate area air measurements for terpenes.

Carbon dioxide was added to the room air in the grow rooms to enhance plant growth. The area concentrations detected in the grow rooms were higher than those found in office environments. There are no specific OELs for short-term area measurements, but the detected concentrations were below OELs established for 8-hour time-weighted exposures.

Limitations

This evaluation was subject to several limitations. This is an expanding industry with several unknowns in terms of workplace exposures and appropriate OELs. The environmental sampling results show exposures and workplace conditions on the days when the evaluation occurred. These results may not be representative of workplace conditions on other days. Interviews were also subject to similar limitations. We were only able to document concerns and symptoms that were reported to us during our evaluation by current employees who chose to participate in the interviews.

Conclusions

Management and employees were concerned about potential exposures to dust, ozone, cannabis compounds, and microbial contaminants such as endotoxin and fungi. Our air sampling found that employees were exposed to endotoxins. We also found that employees working in pre-roll and other production areas have exposures to dust. Surface wipe concentrations indicate the potential exposure to cannabis compounds including Δ9-THC, Δ9-THCA, CBD, and CBN. The health implications for occupational exposure to these cannabis components are unknown. The employees reported allergic and respiratory symptoms, which could potentially be related to cannabis compounds and/or fungal exposures. The employees also reported musculoskeletal symptoms, and we observed employees working in awkward positions and performing repetitive tasks. We also found numerous terpenes in the air. We recommended that the employer and employees take steps to reduce exposures to endotoxins, cannabinoids, dust, repetitive tasks, and noise where possible.

Attribution Statement

N95 and NIOSH Approved are certification marks of the U.S. Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.

Section C: Tables

Table C1. Personal air sampling results for endotoxins in July 2019

Area	Sample duration (minutes)	Total volume (liters)	Endotoxins (EU/m^3)*
Production	126	257	5.8
Mother room	112	229	4.7
Pre-roll	242	394	3.3
Batcher production	143	284	1.4
Harvesting grow room 3	402	794	20.5
Production and bucking room C	432	854	27.6
ACGIH threshold limit value (8-hour time-weighted average)			90

ACGIH = American Conference of Governmental Industrial Hygienists

EU/m^3 = Endotoxin units per cubic meter

* The limit of detection was 0.31 EU per sample

Table C2. Area air sampling results for endotoxins in July 2019

Area	Sample duration (minutes)	Total volume (liters)	Endotoxins (EU/m^3)*
Grow room 7	249	517	ND
Grow room 5	209	413	ND
Rack 2 grow room 3	463	917	9.9
HVAC grow room 3	466	927	3.3
Production and bucking room C	480	954	12.7
Batcher production	302	598	0.7

EU/m^3 = Endotoxin units per cubic meter

ND = not detected

* The limit of detection was 0.31 EU per sample

Table C3. Surface wipe sampling for cannabis compounds (micrograms per 100 square centimeters) in July 2019

	Δ9-THC only	Cannabinoid method*			
Location	Δ9-THC	Δ9-THC	Δ9-THCA	CBD	CBN
Production					
Labeling workstation 10	2.2	ND	11	ND	ND
Cartridges workstation 2	330	140	[6.8]	[4.7]	ND
Batcher between scales	45	22	490	[5.7]	[4.7]
Laptop station 12	2.1	ND	[4.7]	ND	ND
Kitchen					
Cart temporary storage	1.2	ND	ND	ND	ND
Computer workstation	0.21	ND	[3.1]	ND	ND
Laboratory					
Workbench alcohol extractor	22	29	20	ND	ND
Workbench alcohol extractor	74	54	50	ND	ND
Bucking room C					
Empty drying rack	22	26	530	ND	[4.3]
Pre-roll					
Inside door handle #1†	NA	[3.3]	57	ND	ND
Inside door handle #2†	230	NA	NA	NA	NA
Back worktable (preparation)	1.5	ND	26	ND	ND
Front table (repackaging)	1.1	ND	31	ND	ND
Mother room					
Workstation	0.19	ND	[7.7]	ND	ND
Inside door handle†	1.2	NA	NA	NA	NA
Sprayer handle†	NA	[2.2]	59	ND	ND
Grow room 5					
Shelf	0.250	ND	68	ND	ND
Inside door handle†	7.1	NA	NA	NA	NA
Grow room 2					
Inside door handle†	NA	[4.5]	150	ND	ND
Grow room 6					
Shelf	6.6	[3.9]	110	ND	ND
Inside door handle†	17	NA	NA	NA	NA
Grow room 7					
Inside door handle†	NA	[2.8]	64	ND	ND

ND = not detected; NA = not applicable; µg/100 cm^2 = micrograms per 100 square centimeters; [ ] = values in brackets are between the limit of detection and limit of quantification. This means there is more uncertainty associated with these values.

* The limits of detection were 2–3 µg per sample and the limits of quantification were 7.9–10 µg per sample.

† The 100 cm^2 template could not be used so an estimated 100 cm^2 was sampled.

Table C4. Most identified fungi in air samples

Fungal species	Relative abundance
General area samples	
Pseudopithomyces chartarum	20%
Penicillium chrysogenum	13%
Malassezia globosa	9%
Personal breathing zone samples	
Pseudopithomyces chartarum	33%
Aspergillus tamarii	16%
Penicillium citrinum	9%

Table C5. Area air sampling results for ozone in April 2019

Location	Concentration (ppm)
Room F5 – watering plants	ND
Room F5 – drain	ND
Fertilizer room	ND
Sprinkler room – at ozone generator	ND
Sprinkler room – open top of ozonized water tote	0.1
Limit of detection	0.05

ppm = parts per million
ND = not detected

Table C6. Particle monitoring results for one location on April 2019, and five locations (mg/m^3) in July 2019

	Particle size				
Location (date)	PM1	PM2	Respirable	PM10	Total
Pre-roll (April 2019)					
Average	0.017	0.018	0.018	0.025	0.042
Minimum	0.002	0.002	0.002	0.002	0.002
Maximum	6.54	6.54	6.55	6.81	7.56
Pre-roll (July 2019)					
Average	0.019	0.019	0.020	0.025	0.040
Minimum	0.002	0.002	0.002	0.003	0.003
Maximum	0.967	0.967	0.969	1.020	1.780
Auto batcher (July 2019)					
Average	0.043	0.045	0.051	0.084	0.123
Minimum	0.006	0.006	0.006	0.007	0.010
Maximum	0.876	0.945	1.14	2.34	3.67
Grow room 3 (July 2019)					
Average	0.010	0.010	0.010	0.12	0.015
Minimum	0.004	0.004	0.004	0.004	0.004
Maximum	0.060	0.064	0.073	0.124	0.186
Bucking room C (July 2019)					
Average	0.013	0.014	0.015	0.021	0.035
Minimum	0.002	0.002	0.003	0.003	0.003
Maximum	0.068	0.070	0.075	0.128	0.270
Auto batcher (July 2019)					
Average	0.013	0.013	0.013	0.017	0.023
Minimum	0.005	0.005	0.005	0.006	0.007
Maximum	0.145	0.148	0.153	0.204	0.338

mg/m^3 = milligrams per cubic meter

Table C7. Area air sampling results for terpenes (ppb) in July 2019

Terpene	Location								
	Grow Room 7	Grow Room 3	Mother Room	Grow Room 4	Bucking Room Wall	Flower Room 3 HVAC	Flower Room 3 Rack 2		
Sampling time (minutes)	250	253	253	228	482	467	462	MDC	MQC
alpha-bisabolol	ND	ND	ND	ND	ND	ND	ND	0.1–0.3	0.4–0.9
Alpha-humulene	6	[0.5]	[0.6]	[0.4]	15	[0.3]	0.7	0.1–0.3	0.4–1.0
alpha-ocimene	ND	ND	ND	ND	ND	ND	ND	1.8–3.1	11.1–26.5
alpha-pinene	160	30	150	80	140	10	20	0.2–0.4	0.6–1.5
alpha-terpinene	ND	ND	ND	ND	0.8	ND	ND	0.2–0.4	0.6–1.5
beta-caryophyllene	3	3	[1]	[2]	73	2	5	0.1–0.3	1.2–2.9
beta-myrcene	250	94	130	220	1,340	42	140	7.2–17.1	35.9–85.5
beta-ocimene	ND	ND	ND	ND	ND	ND	ND	7.2–17.1	24.8–59.0
beta-pinene	65	14	54	32	170	6	16	0.2–0.4	0.6–1.5
camphene	4	[1]	4	[1]	25	0.7	2	0.2–0.4	0.6–1.5
3-carene	ND	ND	ND	[0.6]	[0.4]	ND	[0.4]	0.2–0.4	0.6–1.5
cis-nerolidol	ND	ND	ND	ND	[0.4]	ND	ND	0.2–0.4	0.6–1.4
gamma-terpinene	ND	ND	ND	ND	1	ND	ND	0.2–0.4	0.6–1.4
geraniol	ND	ND	ND	ND	ND	ND	ND	0.6–1.5	2.4–5.8
(-)-guaiol	ND	ND	ND	[0.8]	ND	ND	ND	0.2–0.4	1.1–2.6
(-)-isopulegol	ND	ND	ND	ND	ND	ND	ND	0.6–0.8	2.4–5.8
limonene	120	79	68	330	2,170	140	370	0.2–0.4	0.6–1.5
linalool	2	3	[1]	4	100	2	6	0.2–0.4	0.5–1.3
p-cymene	[0.7]	ND	[0.5]	[0.4]	2	[0.2]	[0.4]	0.2–0.4	0.3–1.5
terpinolene	[0.4]	ND	[0.7]	ND	9	ND	ND	0.2–0.4	0.3–1.5
trans-nerolidol	ND	ND	ND	ND	ND	ND	ND	0.1–0.3	0.7–1.6

HVAC = heating, ventilation, and air-conditioning system; ppb = parts per billion; ND= not detected at the limit of detection; [ ] = values in brackets are between the minimum detectable and the minimum quantifiable concentration. This means there is more uncertainty associated with these values; MDC = Minimum detectable concentration calculated using sample volumes; MQC = Minimum quantifiable concentration calculated using sample volumes.

Table C8. Direct-reading area air measurements for carbon dioxide in April 2019

Location	Concentration range (ppm)
Grow room 1	1,330–1,440
Grow room 2	1,630–1,700
Grow room 3	1,250–1,660
Grow room 4	1,370–1,650
Grow room 5	1,600–1,650
Grow room 6	1,250–1,320
Grow room 7	1,840–1,890
Clone room	520–780

ppm = parts per million

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects.

However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a preexisting medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- OSHA, an agency of the U.S. Department of Labor, publishes PELs [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry]. These legal limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2007]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States includes the TLVs, which are recommended by the ACGIH®. The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2024].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at https://www.dguv.de/ifa/gestis/gestis-stoffdatenbank/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA (Public Law 91-596) requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions.

Endotoxins

Endotoxins are lipopolysaccharide complexes found in the outer cell wall of Gram-negative bacteria. Gram-negative bacteria are found throughout the environment. Endotoxins are released when bacteria are multiplying or die. Airborne endotoxin exposures between 45 and 400 EU/m^3 have been associated with symptoms of cough, wheeze, shortness of breath, chest tightness, and mucous membrane irritation, and signs of acute airflow obstruction [Farokhi et al. 2018; Thorne and Duchaine 2007]. Chronic health effects that have been associated with airborne endotoxin exposures include chronic bronchitis, bronchial hyperreactivity, chronic airways obstruction, hypersensitivity pneumonitis, and emphysema [Castellan 1995; Duquenne et al. 2013; Liebers et al. 2008; Liebers et al. 2020; Rylander 2006]. Some studies suggest that environmental and occupational endotoxin exposures may protect exposed individuals from developing atopic sensitization [Rylander 2006].

In 2024, ACGIH adopted a TWA of 90 EU/m^3 for an 8-hour working day based on pulmonary function and lower respiratory tract irritation [ACGIH 2024]. In the Netherlands, the Dutch Expert Committee on Occupational Standards has recommended a TWA of 90 EU/m^3 for an 8-hour working day. This exposure level is regarded as a no-observed-effect level based on epidemiologic studies showing evidence of respiratory health effects at concentrations near this level [DECOS 2010].

Δ9-THC

Δ9-THC is a cannabinoid that is the psychoactive component of cannabis. Occupational exposures to cannabinoids can occur through skin absorption, inhalation, and ingestion. The long-term health effects of these occupational exposure routes are presently unknown. There are no OELs for Δ9-THC. Most health effect research of Δ9-THC has focused on inhalation in nonoccupational settings. Short-term effects can include cannabis intoxication, which is characterized by symptoms such as impaired motor coordination, euphoria, anxiety, sensation of slowed time, impaired judgement, and social withdrawal. These symptoms occur during or within 2 hours of cannabis use [American Psychiatric Association 2013].

The National Institute on Drug Abuse [2016] has listed mood changes, diminished memory, and disorientation as short-term health effects of an effective dose of cannabis. Other studies have associated chronic exposure to firsthand cannabis smoke with social anxiety disorder, depressive disorders, psychosis, and respiratory symptoms [National Academies of Sciences, Engineering, and Medicine 2017]. The adverse health effects associated with nonmedicinal and chronic consumption of Δ9-THC derived from *C. sativa* and *Cannabis indica* have been extensively studied and reviewed [Chandy et al. 2024; Hall and Degenhardt 2014; Volkow et al. 2014]. Additional information on health effects can be found at Cannabis Health Effects | Cannabis and Public Health | CDC.

Δ9-THCA, CBD, and CBN

Δ9-THCA, CBD, and CBN are some of the 125 cannabinoids identified in cannabis [Radwan et al. 2021]. These are not psychoactive substances, meaning they do not change a person's mental state by affecting the way the brain and nervous system work. Unlike Δ9-THC, these cannabinoids do not cause intoxication or a "high." Currently, there are no OELs for Δ9-THCA, CBD, or CBN.

Noise

Noise-induced hearing loss (NIHL) is an irreversible condition that progresses with noise exposure. NIHL is caused by damage to the nerve cells of the inner ear and, unlike some other types of hearing disorders, cannot be treated medically [AIHA 2022]. Approximately 25% of U.S. workers have been exposed to hazardous noise [Kerns et al. 2018]. More than 22 million U.S. workers are estimated to be exposed to workplace noise levels above 85 dBA [Tak et al. 2009].

Although hearing ability commonly declines with age, exposure to excessive noise can increase the rate of hearing loss. In most cases, NIHL develops slowly from repeated exposure to noise over time, but the progression of hearing loss is typically the greatest during the first several years of noise exposure [Rosler 1994]. NIHL can result from short duration exposures to high noise levels or even from a single exposure to an impulsive noise or a continuous noise, depending on the intensity of the noise and the individual's susceptibility to NIHL [AIHA 2022].

Noise measurements are usually reported as dBA. A-weighting is used because it approximates the "equal loudness perception characteristics of human hearing for pure tones, relative to a reference of 40 dB SPL at a frequency of 1 kHz [kilohertz]" [Murphy et al. 2022]. This is considered to provide a better estimation of hearing loss risk than using unweighted or other weighting measurements. The dB unit is dimensionless, and it represents the logarithmic ratio of the measured sound pressure level (SPL) to an arbitrary reference sound pressure of 20 micropascals. This is defined as the threshold of normal human hearing at a frequency of 1 kHz. Because the dB is logarithmic, an increase of 3 dB is a doubling of the sound energy. Therefore, an increase of 10 dB is a 10-fold increase, and an increase of 20 dB is a 100-fold increase in sound energy.

Workers exposed to noise should have baseline and yearly hearing tests (audiograms) to evaluate their hearing thresholds and determine whether their hearing has changed over time. Hearing testing should be done in a quiet location, such as an audiometric test booth, where background noise does not interfere with accurate measurement of hearing thresholds. In workplace hearing conservation

programs, hearing thresholds must be measured at frequencies of 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz. NIOSH also recommends testing be done at 8 kHz [NIOSH 1998].

The OSHA hearing conservation standard requires analysis of hearing changes from baseline hearing thresholds to determine if a standard threshold shift (STS) has occurred. OSHA defines an STS as a change in hearing threshold relative to the baseline hearing test of an average of 10 dB or more at 2 kHz, 3 kHz, and 4 kHz in either ear [29 CFR 1910.95]. If an STS occurs, the company must determine if the hearing loss also meets the requirements to be recorded on the OSHA Form 300 Log of Work-Related Injuries and Illnesses [29 CFR 1904.1]. In contrast to OSHA, NIOSH defines a significant threshold shift as an increase in the hearing threshold level of 15 dB or more, relative to the baseline audiogram, at any test frequency in either ear measured twice in succession [NIOSH 1998].

NIOSH has an REL for noise of 85 dBA as an 8-hour TWA. For calculating exposure limits, NIOSH uses a 3-dB time/intensity trading relationship, or exchange rate. Using this criterion, an employee can be exposed to 88 dBA for no more than 4 hours, 91 dBA for 2 hours, 94 dBA for 1 hour, 97 dBA for 0.5 hours, etc. When noise exposures exceed the REL, NIOSH recommends using hearing protection and implementing a hearing loss prevention program [NIOSH 1998].

The OSHA noise standard specifies a PEL of 90 dBA and an AL of 85 dBA, both as 8-hour TWAs. OSHA uses a less conservative 5-dB exchange rate for calculating the PEL and AL. Using the OSHA criterion, an employee may be exposed to noise levels of 95 dBA for no more than 4 hours, 100 dBA for 2 hours, 105 dBA for 1 hour, 110 dBA for 0.5 hours, etc. OSHA requires implementation of a hearing conservation program when noise exposures exceed the AL [29 CFR 1910.95].

Ozone

Low concentrations of ozone exposure can cause skin, eye, and respiratory tract irritation and make symptoms from existing respiratory conditions worse [NIOSH 2019b]. Exposure to low concentrations of ozone may cause symptoms such as headaches, coughing, dry throat, shortness of breath, a heavy feeling in chest, and fluid in the lungs [NIOSH 2019b]. Higher levels of exposure can lead to more severe symptoms including asthma. The level of exposure to ozone depends upon the dose, duration, and work activities. Ozone has a low odor threshold of 0.0076 ppm and an upper threshold of 0.03 ppm [National Center for Biotechnology Information 2024]. The NIOSH REL for ozone is 0.1 ppm and is to be evaluated as a ceiling limit. The current OSHA PEL for ozone is 0.1 ppm as an 8-hour TWA [NIOSH 2007]. Based on the low odor threshold, individuals can detect the compound at levels below those typically associated with adverse health effects.

Section E: References

Δ9-THC

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