Evaluation of Potential Hazards during Harvesting and Processing Cannabis at an Outdoor Organic Farm

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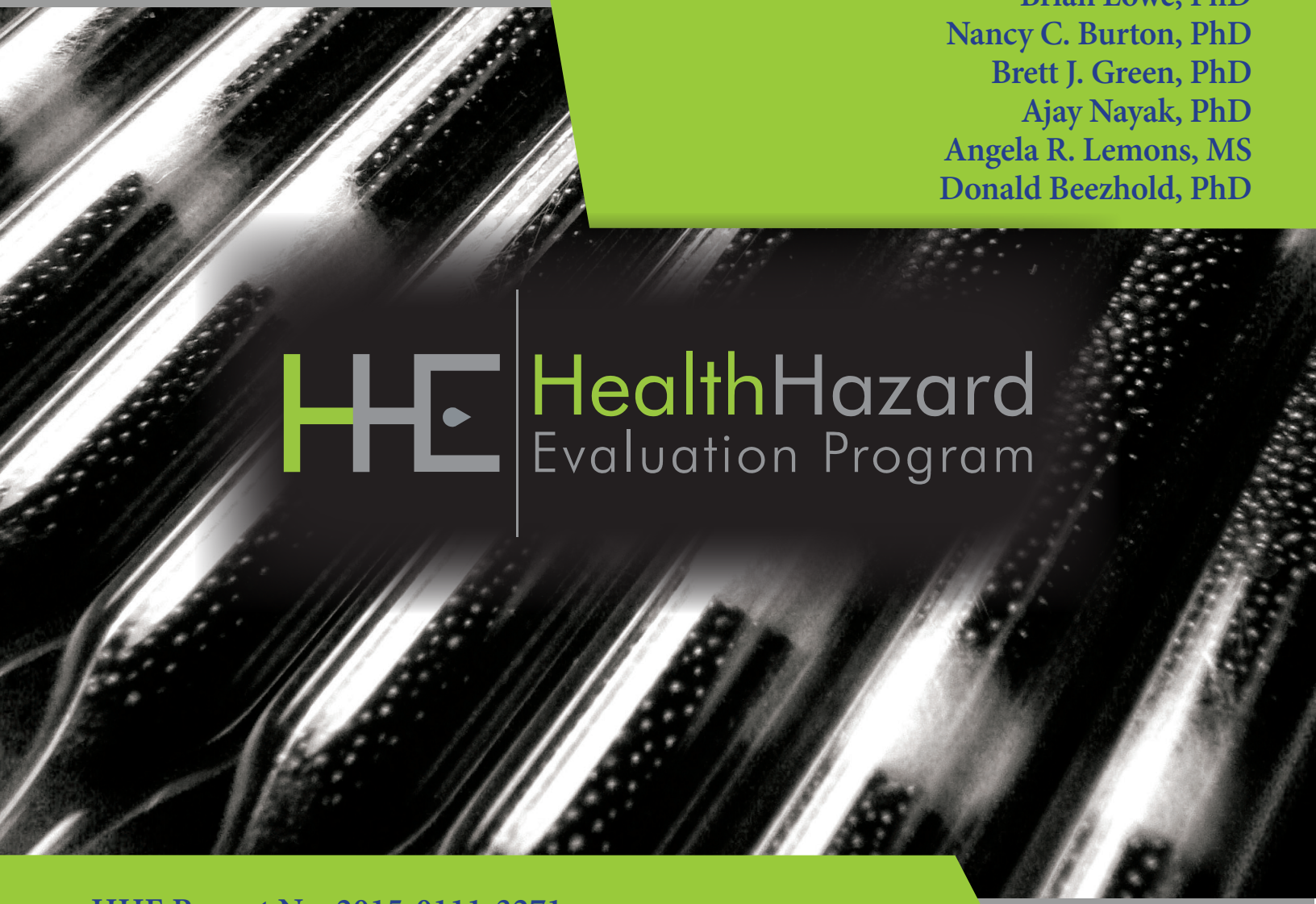

HHE Health Hazard Evaluation Program

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a union representative for an outdoor organic cannabis farm. The representative was concerned about the potential occupational and safety hazards associated with harvesting and processing cannabis.

What We Did

- We visited the farm in August and October 2015.
- We observed work practices and evaluated ergonomic aspects of harvesting and processing tasks.
- We collected air samples for microbes and endotoxin (products released by some bacteria).
- We collected surface wipe samples for tetrahydrocannabinol.
- We interviewed employees about their work, health, and safety concerns.
- We observed demonstrations for machine trimming and nitrogen sealing.

We evaluated cannabis harvesting and processing tasks at an outdoor organic cannabis farm. If hand trimming tasks are performed for longer periods than we observed, the repetitive hand motions create a risk for hand and wrist musculoskeletal disorders. Tetrahydrocannabinol, the psychoactive component in cannabis, was detected on all surface wipe samples. *Botrytis cinerea*, a plant pathogen that can cause allergic reactions in exposed individuals, was the predominant fungal species identified.

What We Found

- Employees were concerned about repetitive hand motions when trimming cannabis.
- Some hand trimming activities required a lot of hand motions, but not a lot of force.
- *Botrytis cinerea* was the main fungal species in the air.
- Actinobacteria was the most frequently identified bacterial phyla in the air.
- We found tetrahydrocannabinol in every surface wipe sample.
- Endotoxin concentrations were all below the occupational exposure limit.

What the Employer Can Do

- Change hook line hanging heights to correspond with typical stem length and employee working technique.
- Provide frequent breaks for employees when they are trimming cannabis by hand.
- Develop a plan to rotate employees among jobs that use different muscle groups.

- Train employees on tool cleaning, lubrication, sharpening, and maintenance.
- Develop a cleaning schedule to remove tetrahydrocannabinol from work and tool surfaces.

What Employees Can Do

- Wear nonlatex gloves when handling cannabis, cannabis products, or equipment that contacts cannabis.
- Wash your skin with soap and water after removing gloves.
- Clean work surfaces after processing cannabis material.

Abbreviations

µg	Microgram
µg/100 cm^2	Micrograms per 100 square centimeters
µg/mL	Micrograms per milliliter
µL	Microliter
ACGIH®	American Conference of Governmental Industrial Hygienists
CFR	Code of Federal Regulations
cm^2	Square centimeters
DECOS	Dutch Expert Committee on Occupational Safety
DNA	Deoxyribonucleic acid
EU	Endotoxin unit
EU/m^3	Endotoxin units per cubic meter
lbs	Pounds
mL	Milliliter
NA	Not applicable
ND	Not detected
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PCR	Polymerase chain reaction
PEL	Permissible exposure limit
rDNA	Ribosomal deoxyribonucleic acid
REL	Recommended exposure limit
THC	delta-9-tetrahydrocannabinol
TLV®	Threshold limit value

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Introduction

The Health Hazard Evaluation Program received a request from the United Food and Commercial Workers International Union to evaluate potential hazards associated with harvesting and processing cannabis, commonly known as marijuana, at an outdoor organic farm. We visited the farm in August and October 2015. We evaluated ergonomic, chemical, and microbial hazards and conducted medical interviews with employees about their health concerns.

Background

The farm was located in the state of Washington, which has legalized cannabis for medicinal and recreational use. At the time of our evaluation, the farm was operated by the owner and three employees. The 5-acre farm grew organic cannabis, vegetables, and fruits without pesticides. The farm grew *Cannabis sativa*, *Cannabis indica*, and a *Cannabis sativa/indica* hybrid.

Chemical and Biological Exposures in Outdoor Farming Environments

Outdoor farming environments have numerous potential occupational exposures of concern. We focused our evaluation on three exposures: endotoxins, microbial biodiversity (fungi and bacteria), and delta-9-tetrahydrocannabinol (THC). Endotoxins are lipopolysaccharide compounds that may be released by the outer cell walls of Gram-negative bacteria and can cause adverse respiratory effects such as chronic bronchitis and asthma [Castellan 1995; Park 2006]. Fungi can produce health effects by four mechanisms: infections (e.g., pulmonary aspergillosis), irritant reactions (e.g., burning, blistering skin), allergic reactions (e.g., allergic rhinitis), and toxic reactions (e.g., gastrointestinal symptoms from ingesting mycotoxins) [Trout et al. 2004]. THC is the psychoactive component in cannabis.

Process Description

According to the farm owner, seeding and cultivation began in February with each cannabis plant grown from seed. Seedlings were cultivated in the greenhouse before they were transplanted to the ground inside hoop houses. Hoop houses are large, semicircular structures that are often made of fabric, which allows sunlight and air to reach plants. The number of plants in each hoop house depended on plant type and size. After transplantation to the hoop house, a screen of green netting was constructed, and the cannabis plant grew through the screen. The screen allowed the cannabis plant to grow an even canopy, maximizing air movement and light to each stem.

During our visit, the farm had approximately 40 plants that each grew to over 8 feet tall and over 6 feet wide. At harvesting, an employee used hand pruners to first remove large outer stems and then continue removing more stems working inward toward the main cannabis plant trunk. The large stem, also known as a cola, was cut in such a way as to form a natural hook at the end furthest from the flower. The stems were transported by hand to the big leafing area. During our visit, the big leafing area was in the same hoop house as the harvested cannabis plants.

In the big leafing area, a cotton line (also known as the hook line) was hung approximately 6–7 feet high from two posts approximately 10 feet apart, and drooped in the middle as stems were added. The cola was hung directly on the hook line via the natural hook cut into the plant during harvesting. The length of these colas was typically 12–18 inches, but one measured 42 inches. At the hook line, outer leaves (which contain little THC) were removed by pulling the leaves off or by cutting with hand pruners. The process of removing these large leaves is known as big leafing. Employees performed big leafing while the cola hung from the cotton line or by removing the cola and holding it with one hand while big leafing with the other. The trimmed colas were taken to the drying area and the big leaf trimmings were collected in a large container. Employees were required to wear powder-free latex gloves during big leafing activities.

The drying area was a separate building that contained wire fencing material stretched between building support columns. Using the natural hook, colas were placed on the wire fencing and allowed to dry. Dehumidifiers and fans were used to speed the drying process. Professional judgment and moisture meters were used to determine if the product was dry enough for destemming.

Destemming is the process of removing the flower from the cola's stem. Employees used two destemming methods. Some employees used bonsai tree trimming scissors to cut individual flowers one at a time. Other employees used a mint tin can with a half-inch hole drilled through the metal (Figure 1). The stem was inserted through the hole, and the flowers were removed by pulling the cola through the tin's drilled hole. As the cola was pulled through the can, the flowers fell into a container lined with a plastic bag. Flowers were collected from both methods and moved to hand trimming. Employees were required to wear powder-free latex gloves during destemming activities.

Hand trimming is the final flower trimming step. It requires small, fine cuts to remove unwanted plant material and make the flower presentable. Employees used two hand trimming methods. Employees choose a hand trimming method based upon personal preference and would switch between the two throughout the day. Employees performed the first hand trimming method while seated at a foldable banquet table covered with a plastic tablecloth. They used a Trim Station™ to perform the second. The Trim Station was a plastic device with dedicated bins to hold the unfinished and trimmed product and tools. Curved cutouts underneath helped hold the device on the user's lap (Figure 2). The Trim Station also contained a black foam ball for cleaning the trimming tool, a jar of trimming tool lubricant, and a plastic bag attached below the trimming area to collect trimmings. Employees used a variety of trimming tools including scissors, bonsai tree pruning scissors without a spring return, and hand pruners with a spring return. The bonsai tree pruning scissors without a spring return appeared to be the preferred tool for this work.

Figure 1. An employee removes the flower from the stem by pulling the stem through a small, drilled hole in a tin can. Photo by NIOSH.

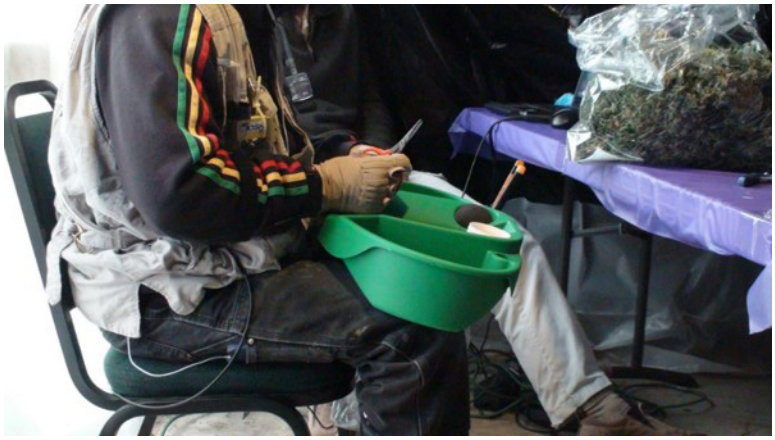

Figure 2. An employee using a Trim Station for the final stage of flower hand trimming. The employee is wearing a CyberGlove on the right hand and a latex glove on the left hand. Photo by NIOSH.

The farm was investigating the use of machine trimmers to automate the trimming process and final packaging with nitrogen sealing to preserve freshness. We observed demonstrations of machine trimming and nitrogen sealing but neither were operational at a production scale during our visit.

Methods

Our objectives were to:

1. Identify potential health hazards to employees related to harvesting and processing cannabis.
2. Determine whether employees were experiencing work-related health symptoms or had health concerns.

Our evaluation included the following: (1) ergonomic evaluation of work tasks, (2) air sampling for endotoxins, (3) assessment of airborne microbiological diversity (fungi and bacteria), (4) surface wipe sampling for THC, and (5) confidential medical interviews with employees.

Ergonomic Evaluation

We observed harvesting tasks and recorded them by photograph and video. Employees confirmed that the harvest activities we observed were typical for the farm.

During big leafing tasks, we asked each of the four employees to simulate the pinch force used to pull leaves off the stem. The pinch force was estimated by having the employee duplicate that amount of force on a digital pinch force gauge (baseline, 100-pound [lb] capacity). Each employee performed three trials and these measurements were averaged.

During the destemming process, employees used either bonsai tree trimming scissors or the tin can method. To assess the force required to remove a bud with the bonsai tree trimming scissors, we asked the three employees performing the destemming process to reproduce that force by closing the scissors onto a digital force gauge (Figure 3). The force measurement represents a simulation of the force required based on the employee's estimate of the exerted force. Each employee performed three trials and these measurements were averaged.

Figure 3. Bud snipping force was estimated by having the employee reproduce the force with the handles of the scissors transmitting the force to the pinch gauge. Photo by NIOSH.

For the tin can method, we taped the end of the stem to a digital force gauge after the end was inserted through the tin can's orifice. This was done to measure the minimum force required to strip buds from the typical length stem when pulling the stem through the tin can. A single employee assisted by holding the tin can while an investigator pulled the stem through the device, using the minimum pull force necessary to strip the buds. We collected 10 measurements to estimate the bud stripping minimum pull force.

For final hand trimming, we evaluated repetitive motion of the hand and fingers with a CyberGlove System, a virtual reality electrogoniometer glove. This form-fitting glove has embedded sensors that span the finger and thumb joints. The device interfaced with a laptop-based data acquisition system with custom-developed software (LabView v 10). All four farm employees wore the electrogoniometer glove during hand trimming; the time ranged from 9 minutes to 35 minutes. For the employee with the most years of trimming experience (most experienced), we recorded a single 9-minute segment of trimming work time. The three other employees had data recording times of 35, 27, and 25 minutes. For these three employees, 54 intervals of 10 seconds each (equal to 9 minutes work time) were randomly selected from the total data recording time to compare to the 9-minute work time for the most experienced trimmer. We counted the motions of the thumb and fingers (closures of the scissors) for 540 seconds of work time for each participant. This was done manually from the time series plotting the hand/finger joint position. Each closure of the scissors has a distinct signature most observable in the index finger metacarpophalangeal joint (knuckle at the base of the finger) and thumb opposition sensors. We created a time history plot from this data, and we manually counted peaks corresponding to reversals in joint angle closure.

Air Sampling for Endotoxins

We collected breathing zone air samples on all four employees during their entire work shift for 3 days. Each sample was collected using three-piece 37-millimeter closed-face cassettes, preloaded with 0.45-micrometer-pore-size endotoxin-free polycarbonate filters. Samples were collected at an air flow rate of 2 liters per minute. Samples were analyzed for endotoxin content with the kinetic-chromogenic procedure using the limulus amebocyte lysate assay [Cambrex 2005]. For these analyses, one endotoxin unit (EU) was equivalent to 0.053 nanograms of endotoxin. The limit of detection was 0.50 EU per sample. We also collected 11 area air samples for endotoxin, including two in the harvesting hoop house, three outside the drying building, and six inside the drying building. We collected three task-based area air samples for endotoxin during various machining activities.

Air Sampling for Microbes

We collected 26 full-shift, personal breathing zone and area air samples using a National Institute for Occupational Safety and Health (NIOSH) two-stage bioaerosol sampler. We collected full-shift personal breathing zone air samples from four employees over 3 days (12 samples in all). We collected 14 area samples: eight in the drying room, three in the greenhouse, and three outdoors. Complete details of the sampling and microbiological diversity analysis are in Appendix B. In brief, we processed the deoxyribonucleic acid (DNA) in the samples and used it to identify varieties of fungi and bacteria by comparing our results

to the National Center for Biotechnology Information database. The results are reported in terms of relative abundance, which is the percentage of each type out of the total in the sample.

Surface Sampling for Tetrahydrocannabinol

We collected 33 surface wipe samples in areas with cannabis processing, before any housekeeping. We also sampled the hand trimming scissor blades after hand trimming but before cleaning, and after cleaning. For each sample we noted the location and recent activities in the area. Where possible, we used a 100-square-centimeter (cm^2) template to sample a consistent surface area. The hand trimming scissor wipe sample area included both blade surfaces (less than 100 cm^2). Surface wipe samples were analyzed for THC using a contract laboratory's internal method. The method used liquid chromatography and tandem mass spectrometry with a limit of detection of 40 ng per sample.

Employees cleaned scissors by either wiping them with an alcohol pad or placing them into a jar of Scissor BUD-e™ cleaner and then wiping them by inserting and removing the scissors multiple times into a black foam ball. While the act of taking a surface wipe sample from the hand trimming scissor blade does remove THC, the "before cleaning" sample is an indication of the THC amount on the hand trimming scissor blades after trimming. The sample collected after the employee cleaned the scissors is an indication of the THC amount left after cleaning and if THC is still present after normal cleaning procedures.

Medical Interviews

We interviewed all four employees about their health and safety concerns related to cannabis processing. We discussed work history and exposure, use of personal protective equipment, and symptoms when working with cannabis. Employees were also asked about long-term health and safety concerns related to their job.

Results and Discussion

Ergonomic Evaluation

During harvesting activities, we observed an employee using hand cutters to remove the cola from the erect cannabis plant. We observed multiple cuts on a single plant. The number of cuts depends on the harvest size. Stems were typically cut at a vertical point below the waist level of the farmer. In many cases, stem removal involved considerable horizontal reaching (Figure 4A). The screen of green netting material creates a barrier restricting how close the farmer can stand with respect to the horizontal distance from the feet to the cutting point. Because of this restriction, the hands are farther from the lower spine (horizontally) when bending to cut plant stems. This creates stooped postures with significant trunk bend with the weight of the trunk and arms creating pressure on the lower spine. This stooping posture is considered a higher risk posture than that in which the feet were closer to the base of the plant and the horizontal distance to the hands was reduced. It does not appear that substantial vertical hand forces are associated with this task due to the light weight of the stems and the cutter. However, any significant pulling on the stem in the upward vertical direction from a

posture such as that in Figure 4B would worsen the biomechanical forces around the lower spine. If the stem is cut cleanly, it does not appear that an upward pulling force is necessary.

(4A) (4B)

Figure 4. Cola removal from the cannabis plant. The screen of green netting restricts how close the harvester can position himself from the base of the plant. Photos by NIOSH.

We observed four employees performing the big leafing process. The working posture in this process was a function of multiple factors:

- Standing vs. sitting
- Height and arm length of employee
- Height of hanging line
- Length of stems, which determines the vertical range of hand positions
- Employee work technique

We observed two big leafing techniques. The first was performed with the cola hanging on the line (Figure 5A). Leaving the cola on the hook line, some employees had to reach above shoulder height. Figure 5B shows a work zone that was above the employee's shoulder height. The second big leafing technique was performed when the employee lifted the stem from the line and performed the big leafing process while holding the stem with his hand at mid-torso level. Because the weight of the cannabis stem is minimal, it likely contributes little to shoulder muscle fatigue. Supporting the mass of the arms accounts for almost all of the effort. Depending on the technique used, the optimal vertical height for the hook line will vary. A combination of repetitive work above shoulder height could also increase the risk for shoulder problems.

(5A) (5B)

Figure 5. (A) Employee on left is shown big leafing from a stem as it hangs on the line. Employee on the right is big leafing the stem by first removing it from the line and holding by hand. (B) The red highlight displays the work zone, which is greater than the employee's shoulder height. Photos by NIOSH.

We asked each employee to use a digital pinch gauge to estimate the pinch force needed to pull leaves off the stem. On the basis of three measurements per person, the estimated peak level pinch forces in the removal of leaves for each employee were 8.3 ± 2.0, 3.4 ± 0.83, and 3.4 ± 0.32 pounds (lbs).

We asked each employee to use a digital pinch gauge to estimate the pinch force needed for destemming. On the basis of three measurements per person for destemming with scissors, the peak level cutting force estimates were 3.9 ± 1.1, 3.2 ± 0.61, and 1.9 ± 0.22 lbs. For destemming with a tin can, the peak pull force averaged 6.2 ± 2.9 lbs over 10 measurements. When using the tin can, it appeared that the pull force is a function of the length of the stem, as longer stems tend to have more buds that are stripped using the pulling motion. Higher pull forces increase the musculoskeletal stress during the task, which may lead to higher risk of cumulative musculoskeletal disorders.

The tin can destemming method required more hand force than cola removal and big leafing because of the can's lightweight construction and flexion within the can. The tin can's metal is not designed for destemming activities or for prolonged use in this manner. An alternate tool made of more durable, sturdy materials that could be attached to a table or work station would create less hand stress and fatigue.

For final hand trimming, the scissor closure motion count measured by the electrogoniometer glove in the 540-second sampling period ranged from 336 to 1,030. Table 1 shows the equivalent repetition rates in motions per second. The most experienced trimmer (more than 10 years) exhibited a higher frequency of hand motions than the two least experienced trimmers (less than 1 year) as displayed in Figure 6. The employee with intermediate experience (more than 1 year but less than 10 years) fell between the highest and lowest experienced employees but more closely resembled the lowest experienced employees. That the number of cuts per unit time is greater (i.e., faster trimming) with the more experienced employee(s) was an expected finding.

Table 1. Summary of repetitive hand motions in hand trimming*

Employee experience	Total observation time (minutes)	Sampling time (minutes)	Average rate (motions/second)	Peak rate (motions/second)†
Most	9.0	9.0	1.91	3.2
Intermediate	35	9.0*	0.95	1.9
Low	25	9.0*	0.62	1.3
Low	27	9.0*	0.79	1.5

*To comprise these 9-minute sampling periods, 54 10-second intervals were selected randomly from the total observation time.

†Calculated from highest count of motions observed in any 10-second interval. Thus, 32 motions observed in a 10-second interval is a peak rate of 3.2 per second.

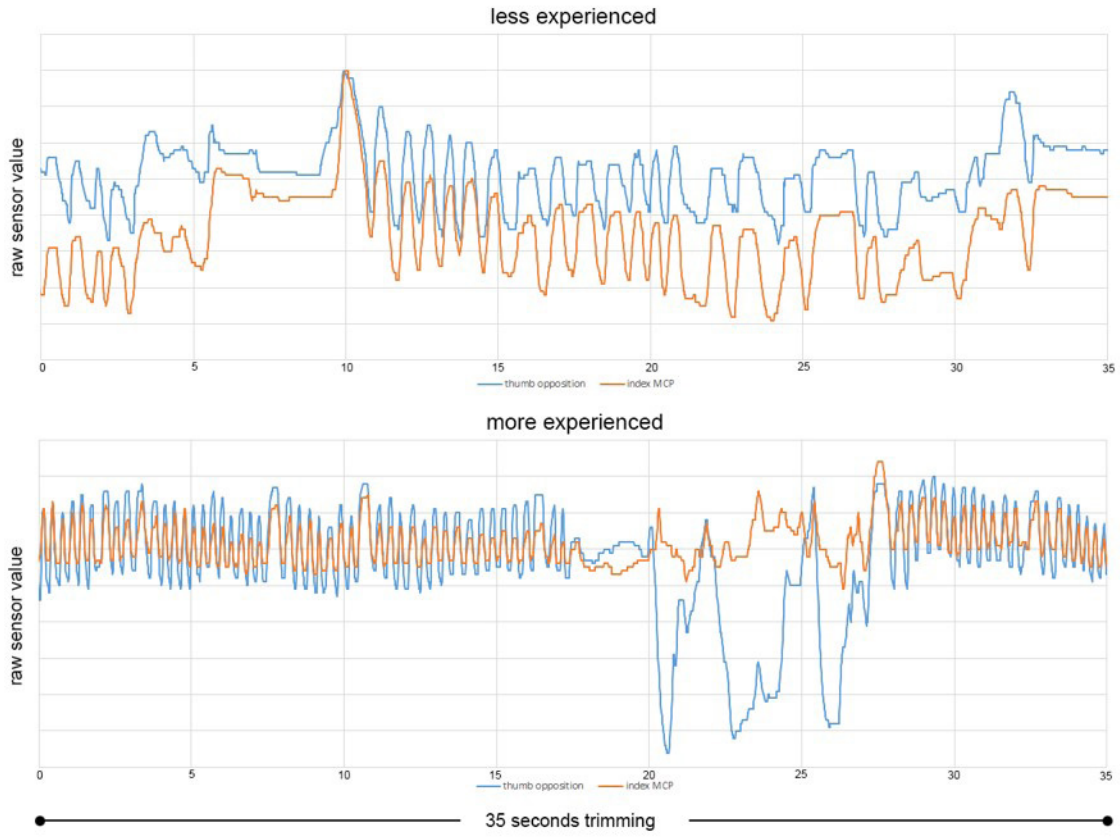

Figure 6. Line graph of hand motion example by level of hand trimming experience. The traces represent thumb opposition joint motion (blue line) and index finger metacarpophalangeal joint motion (orange line) while the y-axis represents reflecting joint angle movement (raw sensor value).

We did not observe any employee performing hand trimming for a full workday. During our visit, only small amounts of product were trimmed because it was late in the harvest season. Employees noted that during the peak season, hand trimming was performed for an entire work day. High frequency motion in hand trimming could increase the risk for hand, wrist, and finger musculoskeletal disorders.

Employees noted that, during hand trimming, the trimmer becomes harder to open and close as sticky residue builds up on it. Most often, employees reported cleaning trimmers only after noticeable resistance was observed. The additional resistance increases the hand, wrist, and finger forces needed for hand trimming and could increase the risk of musculoskeletal disorders.

Air Sampling for Endotoxin

Personal air sampling results for endotoxin are shown in Table 2. Endotoxin concentrations ranged from 2.8 to 37 endotoxin units per cubic meter (EU/m^3). Endotoxin concentrations were highest for all four employees on day 1, when harvesting occurred. Employee 1 harvested the cannabis plant while employees 2, 3, and 4 performed big leafing activities nearby in the same hoop house. During big leafing (Day 2), the maximum endotoxin concentration measured was 24 EU/m^3. Day 2 had the lowest endotoxin concentrations for all four employees. No samples exceeded the Dutch Expert Committee on Occupational Safety (DECOS) recommended limit of 90 EU/m^3 [DECOS 2010]. No occupational exposure limit (OELs) for endotoxin have been established in the United States.

The airborne endotoxin concentrations at the cannabis farm were below those found in other agricultural settings such as an indoor flower greenhouse with 38 employees (range: 0.84 to 1,100 EU/m^3); two indoor herb processing plants with 70 and 90 employees (median endotoxin concentration: 3×10^5 EU/m^3); four peppermint and nine chamomile herb farm indoor processing operations (median for endotoxin peppermint farms: 1×10^6 EU/m^3; median endotoxin for chamomile farms: 1.8×10^4 EU/m^3); and an indoor hemp processing plant with seven employees (mean endotoxin concentration: 1.9×10^4 EU/m^3) [Dutkiewicz et al. 2001; Fishwick et al. 2001; Skórska et al. 2005; Thilsing et al. 2015].

Endotoxin concentrations in area air samples, provided in Table A1, Appendix A, ranged from not detected to 15 EU/m^3. The highest area air sample endotoxin concentrations were found in the hoop house on the first day of sampling during harvesting and big leafing activities. Endotoxin was not detected in the three outdoor area air samples collected outside the drying house. Endotoxin concentrations during task-based sampling for three machining processes (Table A2, Appendix A) were 2.0 EU/m^3 for the large tumbling machine trimmer, 3.6 EU/m^3 for the horizontal machine trimmer, and 13 EU/m^3 for nitrogen sealing. The nitrogen sealing demonstration took place in the hoop house where harvesting had been performed 2 days earlier, while the two machine trimming demonstrations were performed in the drying house.

Table 2. Personal breathing zone air sampling for endotoxins on October 27–29, 2015

Job/Activity	Sample time (minutes)	Total volume (liters)	Concentration (EU/m^3)
Harvesting – October 27, 2015			
Employee 1	466	950	37
Big leafing/gross trimming – October 27, 2015			
Employee 2	471	938	20
Employee 3	469	934	22
Employee 4	466	928	24
Big leafing/gross trimming/destemming – October 28, 2015			
Employee 1	415	818	6.1
Employee 2	414	798	2.9
Employee 3	418	812	3.8
Employee 4	409	795	2.8
Destemming/hand trimming – October 29, 2015			
Employee 1	486	951	17
Employee 2	479	964	15
Employee 3	480	929	21
Employee 4	483	940	19
ACGIH® TLV®			NA
NIOSH REL			NA
OSHA PEL			NA
DECOS			90

ACGIH = American Conference of Governmental Industrial Hygienists
NA = Not applicable
OSHA = Occupational Safety and Health Administration
PEL = Permissible exposure limit
REL = Recommended exposure limit
TLV = Threshold limit value

Air Sampling for Microbes

Bacterial Analysis

A total of 1,077 bacterial sequences were identified; these were clustered into 639 taxonomic units. Figures 7A–7D show the relative abundance by phylum (7A), class (7B), most common bacterial taxa (7C), and sampling location (7D). The relative abundance is the percentage of each bacterial species compared to the total number of bacterial species. The bacterial sequences were derived from the bacterial phyla listed in Figure 7A. The most predominant phyla identified in the area and personal samples included Actinobacteria (45%), Proteobacteria (26%), Firmicutes (15%), and Bacterioidetes (9%) (Figure 7A). An additional 11 bacterial phyla were identified in the analysis and accounted for 4% of bacterial sequences (Figure 7A).

Figure 7B depicts the relative abundance of individual bacterial classes for the four most prominent bacterial phyla. Bacterial classes with over 10% relative abundance included Actinobacteria (43%), Alphaproteobacteria (16%), and Bacilli (13%) (Figure 7B). Analysis of the individual species is shown in Figure 7C. The most abundant species identified in the area and personal samples accounted for 7% of bacterial sequences and consisted of three genera: *Arthrobacter spp.* (2.5%), *Nocardioides spp*. (2.5%), and *Bacillus spp.* (2.1%) (Figure 7C). In some field and media negative controls, bacterial DNA derived from species such as *Bradyrhizobium elkanii* were identified and subtracted from the personal and area air sampling results to identify potential contaminant bacterial DNA and normalize all results.

Overall, no substantial differences in bacterial phyla relative abundance were observed among the different sampling locations. Gram-positive bacteria belonging to the phylum Actinobacteria, also known as Actinomycetes, comprised 47% in personal air samples, 51% in greenhouse samples, 46% in drying room samples, and 23% in outdoor area samples (Figure 7D). Approximately, 40% of bacterial phyla were endotoxin-producing Gram-negative bacteria. These gram-negative endotoxin-producing bacteria, as well as the Gram-positive Actinomycetes, are known to cause adverse health effects, such as hypersensitivity pneumonitis, chronic bronchitis, organic dust toxic syndrome, asthma, and allergic sensitization [Lacey and Crook 1988; Mackiewicz et al. 2015; Park et al. 2006; Pepys et al. 1963].

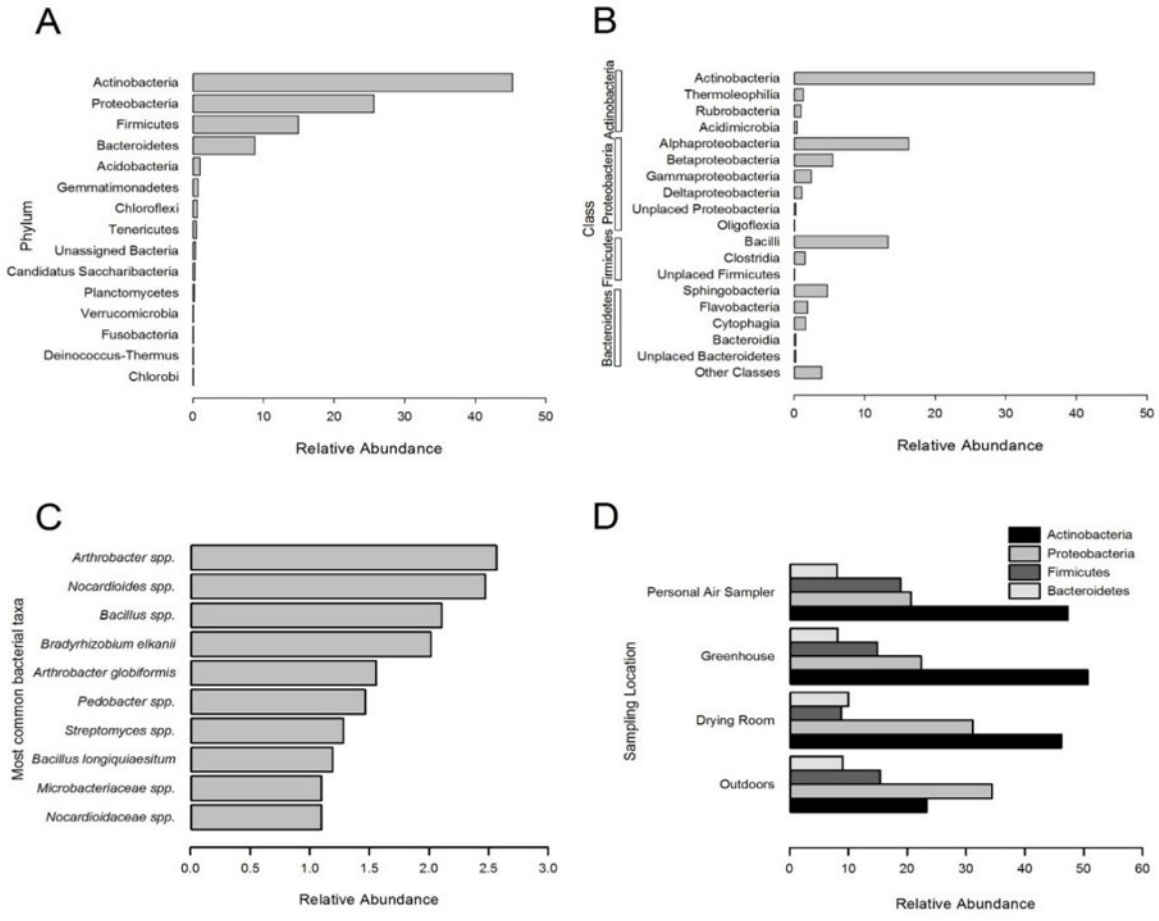

Figure 7. Four bar charts that depict bacterial relative abundance by phylum (A), class (B), most common bacterial taxa (C), and sampling location (D).

Fungal Analysis

Fungal DNA sequences derived from 985 sequences were clustered into 216 taxonomic units. Figures 8A–8D are horizontal bar graphs showing the relative abundance by phylum (8A), class (8B), most common fungal taxa (8C), and sampling location (8D). The relative abundance is the percentage of each fungal species compared to the total number of fungal species. The fungal sequences were placed into four fungal phyla and included the Ascomycota (53%), Basidiomycota (46%), Zygomycota (1.2%), and Glomeromycota (0.5%) (Figure 8A). Figure 8B shows the relative abundance of classes derived from the two most prevalent fungal phyla, the Ascomycota and Basidiomycota. The Agaricomycetes (Basidiomycota) and the Leotiomycetes (Ascomycota) were the most abundant classes accounting for 42% (Agaricomycetes) and 38% (Leotiomycetes) of fungal sequences. The Agaricomycetes represent a class of fungi that decays wood and produces a wide diversity of fruiting structures such as mushrooms. In contrast, the Leotiomycetes are a class placed in the Ascomycota and includes a diverse group of fungi, many of which are plant pathogens that break down agricultural products. In the present study, *Botrytis cinerea*, a plant pathogen of *Cannabis sativa* that causes grey mold, was the most common fungal sequence in the analysis of personal and area samples and accounted for 34% of fungal sequences (Figure 8C).

Figure 8D depicts the analysis of fungi in area and personal samples. Sequences placed in the Basidiomycota were the predominant class identified in outdoor samples (91%) and within the drying room (70%) (Figure 8C). Greenhouse samples included similar proportions of Ascomycota (49%) and Basidiomycota (47%), as well as some Zygomycota (2.7%). Personal air samples were dominated by sequences placed in the Ascomycota (87%, Figure 8D), and the most prevalent species was the fungal plant pathogen *Botrytis cinerea*. This was the major fungal species identified in the air samples, making up almost 60% of the fungi detected in personal air samples, 19% of the drying room area air sample, 18% of the greenhouse area air sample, and 6% in the outdoor sample. *Botrytis cinerea* is the most significant fungal pathogen of *Cannabis* and can affect the seedlings, stems, and buds [McPartland 1996; Rodriguez et al. 2015]. *Botrytis* has been observed to be among the most frequently detected fungal genera (10%–32% relative abundance) in European greenhouse environments [Monsó et al. 2002; Radon et al. 2002]. Personal exposure to *B. cinerea* has been shown to cause allergic sensitization in occupational settings such as green bell pepper greenhouses [Groenewoud et al. 2002a], chrysanthemum greenhouses [Groenewoud et al. 2002b], and table grape farms [Jeebhay et al. 2007].

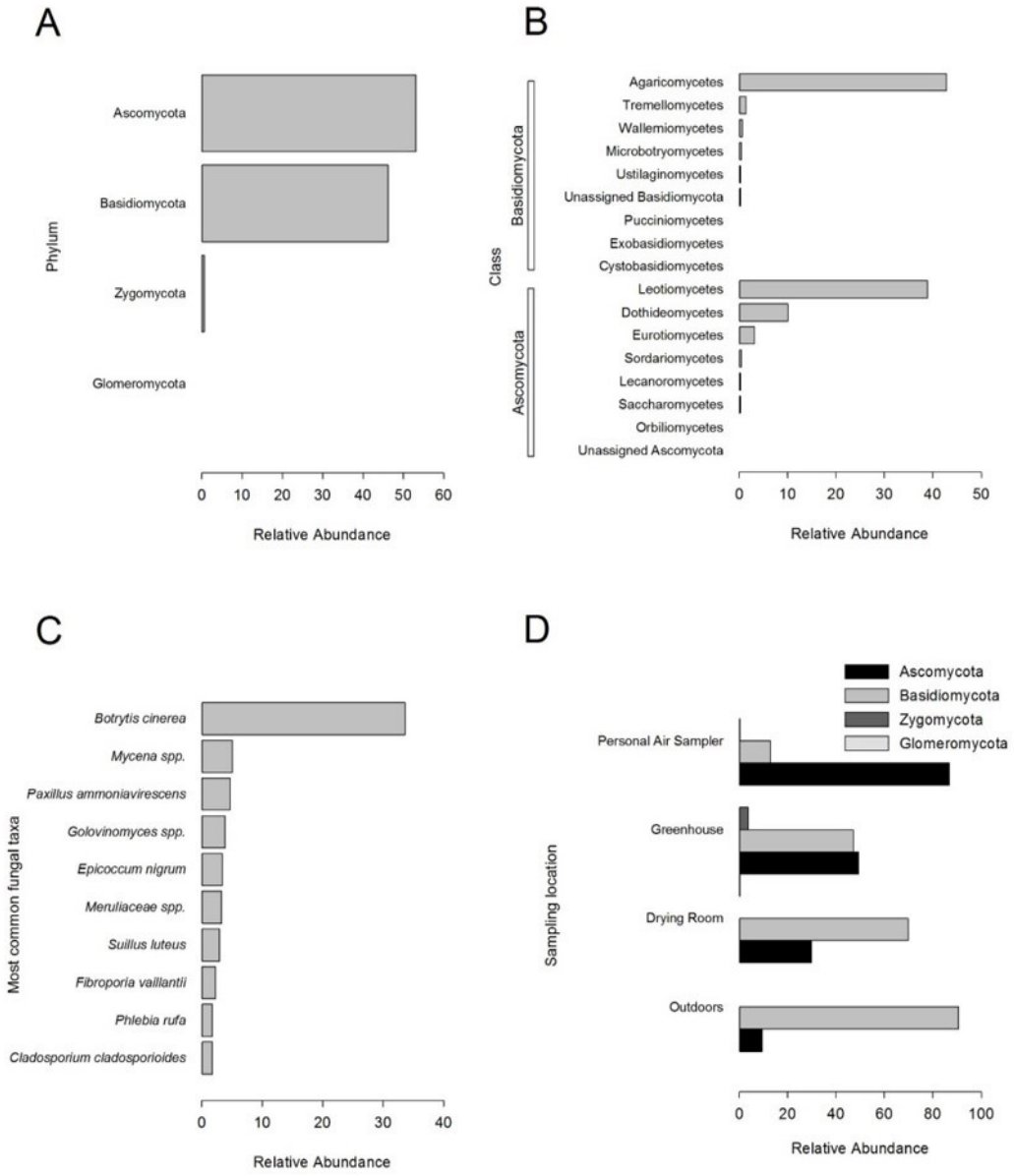

Figure 8. Four bar charts that depict the fungal relative abundance by phylum (A), class (B), most common fungal taxa (C), and sampling location (D).

Microbiological exposures including endotoxin, bacterial, and fungal species may place workers at risk of allergic sensitization and respiratory issues. For example, *B. cinerea* has previously been linked to a hypersensitivity pneumonitis condition commonly known as wine grower's lung [Popp et al. 1987].

Tetrahydrocannabinol

All 27 surface wipe samples were collected in cannabis production areas and had detectable levels of THC. The surface wipe results ranged from 0.17 to 210 micrograms (µg) per 100 cm^2 (µg/100 cm^2). Table A3, Appendix A shows all 27 surface wipe sample levels. In an evaluation of 30 indoor cannabis grow operations to investigate potential law enforcement employee exposures, surface THC levels ranged from not detected to 2,000 µg/100 cm^2 with a geometric mean of 0.37 µg/100 cm^2 [Martyny et al. 2013].

We collected six hand trimming scissor blade surface wipe samples. For three employees, a sample was collected after hand trimming but before cleaning as well as after cleaning. The THC levels before cleaning ranged from 61 to 180 µg per sample, while the levels after cleaning ranged from 25 to 67 µg per sample. Table 3 shows the wipe sample result for each employee both before and after cleaning. We cannot determine if the reduction in THC is due to the cleaning procedure or the removal due to surface wipe sampling.

Table 3. Scissor surface wipe sampling for THC before and after cleaning on October 28, 2015*

Sample	Micrograms per sample
Employee 1	
Before cleaning	180
After cleaning	67
Employee 2	
Before cleaning	61
After cleaning	41
Employee 3	
Before cleaning	110
After cleaning	25

*Scissors were sampled after hand trimming but before cleaning and sampled again immediately after cleaning.

Raw cannabis plant material consists of various cannabinoid acids: (1) tetrahydrocannabinolic acid, (2) cannabidiolic acid, and (3) cannabichromenic acid [Burstein 2014]. THC is the psychoactive component of cannabis, and previous cannabis exposure assessments have typically involved sampling for THC [Martyny et al. 2013]. However, raw cannabis plant material contains a number of precursor acids that must be decarboxylated in order to form the psychoactive and medicinal components. Decarboxylation most commonly occurs through heat application but may also result from aging. Because of the lack of heat applications, surface wipe sample results may under report the range of THC compounds present including the THC precursor acid (tetrahydrocannabinolic acid).

THC surface wipe sample results should be considered semiquantitative. Samples with high concentrations required multiple dilutions while samples with lower concentrations did not require as many or any additional dilutions to quantify the THC concentrations. The contract

laboratory noted that the recovery was dependent on the THC concentration and that the reported values were likely an underestimate of the actual concentrations. Therefore, the THC concentrations should be considered as semiquantitative and used to designate areas of higher THC contamination. Currently, there are no OELs for THC.

We did not collect air samples for THC. A previous study of 30 indoor grow operations indicated that measurable airborne THC levels were unlikely [Martyny et al. 2013]. The study reported only one detectable air sample (0.70 µg per sample) while the rest did not detect THC (limit of detection 0.10 µg per sample).

Medical Interviews

We interviewed all four employees at the farm including the owner/operator. They reported prior work with cannabis with a range of less than 1 year to 17 years. Employees stated that harvesting season (summer–fall) is the busiest time at the farm. All interviewed employees reported performing several tasks at the farm including cultivating, cutting, and trimming of cannabis.

All interviewed employees stated that they always used powder-free latex or work gloves when handling cannabis. However, we did observe employees not wearing gloves while handling cannabis. The use of powdered latex gloves may lead to adverse health effects ranging from allergic dermatitis to anaphylaxis and occupational asthma [Meade et al. 2002; Sussman et al. 2002].

Employees were also asked whether they experienced symptoms that might be related to working with cannabis. None reported any symptoms or health effects, such as rashes on the skin or allergic reactions, which have been previously shown to be associated with cannabis exposure [Decuyper et al. 2015]. No employee reported hand, wrist, or shoulder symptoms or other musculoskeletal problems. However, employees did express concerns about whether they might develop long-term musculoskeletal problems as a result of the way they trim the cannabis. Employees also raised concerns about slips, trips, and falls. They also mentioned concerns about the safety of the proposed use of automated trimmers during operation and cleaning.

Research on occupational health issues in the cannabis industry is limited. A study of 30 indoor grow facilities in Colorado evaluated potential exposures to first responders [Martyny et al. 2013]. That study identified potential dermal exposures to THC, fungal spores (predominantly *Cladosporium* and *Penicillium* species), pesticides (primarily pyrethroids), carbon monoxide, and carbon dioxide. The state of Colorado has issued occupational safety and health guidance for the cannabis industry [CDPHE 2017].

Conclusions

We evaluated hazards associated with harvesting and processing cannabis at a small outdoor organic farm. The four employees reported no health effects. Our findings indicate that the employees have exposures to highly repetitive and forceful work, most notably during hand trimming activities. These exposures increase their risk of musculoskeletal disorders. THC surface wipe concentrations indicate the potential for dermal and ingestion exposures. However, the health implications from occupational exposure to THC is unknown. Airborne

exposure to Actinobacteria and fungus like *B. cinerea* can increase the risk of allergic and respiratory symptoms. The employer should take measures to minimize these hazards.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the farm to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the farm.

Our recommendations are based on an approach known as the hierarchy of controls. This approach 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 feasible, administrative measures and personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Improve the tin can bud removal method to eliminate tool flexion during destemming. Replace the tin can with a new tool made of more durable materials that can be attached to a table or work station to lessen hand stress and fatigue.
2. Remove the screen of green netting during harvesting to allow the harvester to stand closer to the cannabis plant. This change will reduce exposure to awkward postures.
3. Standardize procedures so that hook line hanging heights are in an optimal work zone consistent with employee size and working technique. Determine a hook line hanging height that is compatible with the typical stem length and working technique preferred (sitting or standing) so that the upper arms are not in an elevated static posture. The hook line height should keep the hands below shoulder height to the extent possible.
4. Consider hook line configurations that have standing and sitting options or alternate sitting/standing.
5. Provide as much natural ventilation as possible by raising the sides of the hoop house and opening doors when it is occupied.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Develop a job rotation plan to move employees working in high hand and finger

motion frequency tasks to other jobs that require using different muscle-tendon groups. An effective job rotation plan will reduce the risk of musculoskeletal disorders.

2. Provide frequent breaks for employees working in high hand and finger motion frequency tasks such as hand trimming.
3. Develop a cleaning schedule to remove THC from work and tool surfaces.
4. Provide training to employees on the cleaning, lubrication, sharpening, and maintenance of tools according to manufacturer recommendations.
5. Encourage employees to report any work-related symptoms to their supervisor and to their healthcare provider.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Wear nonlatex gloves when handling cannabis or equipment that may be contaminated with THC. Many types of glove materials are available, such as nitrile, polyvinyl chloride, neoprene, and polyvinyl alcohol. Each glove material provides different levels of protection from chemicals, and varying levels of cut, tear, abrasion, puncture, and thermal resistance.
2. Wash your skin with soap and water after removing gloves.

Appendix A: Tables

Table A1. Area air sampling for endotoxin on October 27–29, 2015

Job/Activity	Sample time (minutes)	Total volume (liters)	Concentration (EU/m^3)*
Harvesting/big leafing/gross trimming – October 27, 2015			
Front of harvesting hoop house	435	860	13
Back of harvesting hoop house	434	868	15
Trimming area of drying house	450	895	ND
Next to drying plants in drying house	450	909	ND
Outside new drying house	421	836	ND
Big leafing/gross trimming/destemming – October 28, 2015			
Trimming area of drying house	423	830	ND
Next to drying plants in drying house	412	812	ND
Outside new drying house	409	795	ND
Destemming/hand trimming – October 29, 2015			
Trimming area of drying house	522	1022	1.5
Next to drying plants in drying house	525	1016	1.7
Outside new drying house	504	978	ND
ACGIH TLV			NA
NIOSH REL			NA
OSHA PEL			NA
DECOS			90

ND = Not detected

*The minimum detectable concentration of endotoxin ranged from 0.51 EU/m^3 to 0.63 EU/m^3.

Table A2. Task-based area air sampling for endotoxin on October 28–29, 2015

Job/Activity	Sample time (minutes)	Total volume (liters)	Concentration (EU/m^3)
Next to large tumbler	131	252	2.0
Next to machine trimming	198	388	3.6
Nitrogen sealing	46	89	13
ACGIH TLV			NA
NIOSH REL			NA
OSHA PEL			NA
DECOS			90

Table A3. Surface wipe sampling for THC on October 28, 2015

Location	Level (µg per 100 cm^2)
Drying building	
Table surface in front of dry trimmer	0.51
Table surface to right of dry trimmer	0.81
Dry trimmer exit chute	100
Preparation table	0.67
Preparation table near drying cannabis	2.5
Wood chest	3.9
Top of heater (not turned on) near hand trimming	5.9
Table surface directly in front of dry trimmer #2	120
Table surface to the right of dry trimmer #2	6.9
Table surface to the left of dry trimmer #2	5.5
Dry trimmer #2 chute	37
Dry trimmer #2 inside lid	1.8
Dry trimmer #2 outside lid	1.5
Hand trimming table	130
Hand trimming table #2	20
White chair seat at trimming table	140
Hoop house	
Folding table	0.17
Trimming station after hand trimming	45
Trimming station after hand trimming #2	1.0
Grey table near hand trimming station	210
Grey table near hand trimming station #2	0.27
Folding chair at trimming station*	2.9
White chair near hood line*	5.2
Metal chair in sitting area*	2.7
Wood table in sitting area	1.4
Round table in sitting area	2.8
Chair near big leafing	2.9

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

Appendix B: Methods

Air Sampling for Microbial Genomic Analysis

We collected aerosols at 2 liters per minute using a two-stage sampler with two cyclones depositing into microcentrifuge tubes and onto a polytetrafluoroethylene filter. The bioaerosol samplers allowed for the collection of particles across three size fractions: > 4.1 micrometers, 1.0–4.1 micrometers, and < 1.0 micrometer aerodynamic diameter. The three size cut samples taken with each bioaerosol sampler were aggregated for genomic DNA analysis.

Genomic DNA Extraction from Air Samples

We processed air samples separately for fungal and bacterial DNA extraction using the Roche High Pure Polymerase Chain Reaction (PCR) Template kit as previously described [Rittenour et al. 2012, 2014]. For air samples, including field and media blank controls, we combined each stage from the NIOSH BC251 air sampler prior to DNA extraction. We sectioned the after filter into six pieces with a scalpel using aseptic methods. We placed these pieces into a 2-milliliter (mL) bead-beater tube containing 300 milligrams of glass beads as described above. We placed the tubes in liquid nitrogen for 30 seconds and processed in a bead beater 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 fungal and bacterial DNA from the samples. The lysis buffer was added to the 2 mL bead-beater tube containing the macerated filter material. We processed the tubes with a bead beater 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 incubated at 70°C for 10 minutes. We washed the sample and eluted in 100 µL of isopropanol as recommended by the manufacturer.

Fungal ITS and Bacterial 16S rDNA Amplification, Cloning, and Sanger Sequencing

We targeted fungal ribosomal deoxyribonucleic acid (rDNA) for PCR amplification as previously described [Rittenour et al. 2012, 2014]. Briefly, fungal rDNA sequences were amplified with the primer pair Fun18Sf (TTGCTCTTCAACGAGGAAT) and ITS4 (TCCTCCGCTTATTGATATGC). The fungal internal transcribed spacer-1 (ITS1) and ITS2 regions were amplified with Platinum Taq DNA polymerase (Invitrogen) according to the methods previously described [Rittenour et al. 2012, 2014]. 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 ran the purified product (8 µL) on a 1% agarose gel containing 1 µg/mL ethidium bromide and examined for amplicons with ultraviolet light.

We amplified bacterial 16S rDNA sequences with the use of the highly conserved primer pair p8FPL (AGTTTGATCCTGGCTCAG) and p806R (GGACTACCAGGGTATCTAAT) [McCabe et al. 1999]. We amplified the bacterial 16S rRNA genes with Invitrogen Platinum Taq DNA polymerase by a modified method of [McCabe et al. 1999]. The PCR conditions included initial denaturation at 95°C for 4 minutes, followed by 33 cycles of denaturation at 94°C for 1 minute, annealing at 55°C for 1 minute, extension at 72°C for 2 minutes, and completion with a final extension at 72°C for 10 minutes. We ran three 50-µL replicate PCR reactions for each sample with the use of 5 µL of DNA template. We combined the replicates, and the rDNA amplicons were purified with a Qiagen PCR purification kit according to the manufacturer's instructions. We ran the purified product (8 µL) on a 1% agarose gel containing 1 µg/mL ethidium bromide and examined for amplicons with ultraviolet light.

We separately cloned fungal and bacterial 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 [Rittenour et al. 2012, 2014]. We selected positive colonies (as determined colorimetrically by the inactivation of the lacZ gene) and cultured 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, and sent for Sanger sequencing of the bacterial 16S insert from Genewiz, Inc. Inserts were sequenced in both directions, allowing for sequence analysis of the 16S region.

Sequencing results were downloaded as ".ab1" chromatogram files from Genewiz Inc. Vector sequence data were trimmed and forward and reverse sequences were assembled using Biomatters Geneious R7 Software. Then we sequenced the DNA to identify which varieties of bacteria were present in the air. 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 [Rittenour et al. 2012, 2014; Schloss et al. 2009]. Sequences representative of each operational taxonomic unit were then used in a Basic Local Alignment Search Tool search against the National Center for Biotechnology Information database.

Appendix C: Occupational Exposure Limits and Health Effects

Endotoxins

Endotoxins are found throughout the agricultural environment. Endotoxins are found in the cell wall of Gram-negative bacteria and are released when the bacterial cell is lysed (broken down) or when it is multiplying. In experimental studies, human volunteers exposed via inhalation to high levels of endotoxin experience airway and alveolar inflammation as well as chest tightness, fever, and malaise, and have an acute reduction in lung function, as measured by the forced expiratory volume in one second [Castellan 1995]. Airborne endotoxin exposures between 45 and 400 EU/m^3 have been associated with acute airflow obstruction, mucous membrane irritation, chest tightness, cough, shortness of breath, fever, and wheezing [Thorne and Duchaine 2007]. Chronic health effects that have been associated with airborne endotoxin exposures include asthma, chronic bronchitis, bronchial hyper-reactivity, chronic airway obstruction, hypersensitivity pneumonitis, and organic dust toxic syndrome [Duquenne et al. 2013; Rylander 2006]. Some studies suggest that high environmental and occupational endotoxin exposures may protect exposed individuals from developing atopic sensitization [Rylander 2006].

Rylander and Jacobs have suggested an occupational threshold concentration for endotoxin equivalent to 100 EU/m^3 of air to prevent airway inflammation [Rylander and Jacobs 1997]. No accepted OELs have been developed in the United States because of the variability of sampling and analytical methods, and because of a lack of data showing a consistent dose-response relationship [AIHA 2005; Duquenne et al. 2013]. In 2010, DECOS recommended a health-based OEL for airborne endotoxin of 90 EU/m^3 as an 8-hour time-weighted average [DECOS 2010].

THC

THC is the psychoactive component of cannabis. The health effects from an effective dose of cannabis may include mood changes, diminished memory, and disorientation [NIDA 2016]. Health effects from long-term occupational exposures are unknown, in part because occupational exposures to THC are thought to be predominantly through skin absorption and ingestion. Past THC and health effects research has focused primarily on inhalation in nonoccupational settings.

The adverse health effects associated with nonmedicinal and chronic consumption of THC derived from *Cannabis sativa* and *Cannabis indica* have been extensively studied and reviewed [Hall and Degenhardt 2014; Volkow et al. 2014]. In contrast, the short-term and long-term health effects of occupational exposure to *Cannabis spp*. material are not well described in the literature. In addition to THC and cannabinol, cannabis production employees may be exposed to a variety of plant-derived materials such as leaves, buds, sap/exudate, flowers, and pollen when handling the plant during cultivation and processing procedures. They can also encounter other contaminant and plant pathogen sources such as

bacteria and fungi. These secondary exposures may result in occupational byssinosis, a lung disease associated with textile fibers (cotton, hemp, etc.) [Valic et al. 1968; Zuskin et al. 1990].

Hemp

Hemp, also derived from *Cannabis sativa*, is used for a variety of purposes including fiber, rope, paper composites, food, and oil and oil-based products [USDA 2000]. Occupational hemp exposure can result in a variety of clinical symptoms including sinusitis, byssinosis, and reductions in lung function [Zuskin et al. 1990, 1992, 1994]. Employees who directly handle the plant are particularly at risk [Barbero and Flores 1967; Valic and Zuskin 1971; Zuskin et al. 1990, 1994]. Transdermal applications of medicinal cannabis demonstrate that occupational dermal absorption is a potential exposure route [Goldsmith 2015]. Other studies have also demonstrated dermal reactions such as an urticarial rash (hives) in subjects who directly contact cannabis [Basharat et al. 2011; Ozyurt et al. 2014]. Urticaria has also occurred in forensic specialists and law enforcement officers following the handling of cannabis [Herzinger et al. 2011; Majmudar et al. 2006; Mayoral et al. 2008; Williams et al. 2008]. Several of these plant components have recently been shown to produce high molecular weight proteins that can result in the allergic sensitization following personal exposure [Nayak et al. 2013].

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