HHS Public Access

Author manuscript

Am J Ind Med. Author manuscript; available in PMC 2022 March 03.

Published in final edited form as:

Am J Ind Med. 2019 October ; 62(10): 874–882. doi:10.1002/ajim.23025.

Potential occupational and respiratory hazards in a Minnesota cannabis cultivation and processing facility

James R. Couch, PhD[1], **George R. Grimes, MD**[1,2], **Douglas M. Wiegand, PhD**[1], **Brett J. Green, PhD**[3], **Eric K. Glassford, MS**[1], **Leanard M. Zwack, ScD**[1], **Angela R. Lemons, MS**[3], **Stephen R. Jackson, PhD**[3], **Donald H. Beezhold, PhD**[3]

[1] Division of Field Studies and Engineering, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Cincinnati, Ohio

[2] Epidemic Intelligence Service, Centers of Surveillance, Epidemiology, and Laboratory Services, Centers for Disease Control and Prevention, Cincinnati, Ohio

[3] Health Effects Laboratory, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Morgantown, West Virginia

Abstract

Background—Cannabis has been legalized in some form for much of the United States. The National Institute for Occupational Safety and Health (NIOSH) received a health hazard evaluation request from a Minnesota cannabis facility and their union to undertake a health hazard evaluation.

Methods—NIOSH representatives visited the facility in August 2016 and April 2017. Surface wipe samples were collected for the analysis of delta-9 tetrahydrocannabinol (Δ9-THC), delta-9 tetrahydrocannabinol (Δ9-THCA), cannabidiol, and cannabinol. Environmental air samples were collected for volatile organic compounds (VOCs), endotoxins (limulus amebocyte lysate assay), and fungal diversity (NIOSH two-stage BC251 bioaerosol sampler with Internal Transcribed Spacer region sequencing analysis).

Results—Diacetyl and 2,3-pentanedione were identified in both initial VOC screening and subsequent sampling at levels well below the NIOSH recommended exposure limits (RELs). Endotoxin concentrations were highest during processing activities, while Internal Transcribed Spacer region sequencing revealed that the Basidiomycota genus, *Wallemia*, had the highest relative abundance.

Conclusions—Δ9-THC was identified throughout the facility. Although diacetyl and 2,3-pentanedione were identified, the exposures were below the NIOSH REL. Exposures to diacetyl and 2,3-pentanedione were highest in the decarboxylation oven where heat transference was greatest. Endotoxin levels were highest during grinding operations when aerosol generating activities occurred. The findings indicate that potential health hazards of significance are present during cannabis processing, and employers should be aware of potential exposures to VOCs,

Correspondence George R. Grimes MD, MPH, Division of Field Studies and Engineering, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Cincinnati, Ohio; 1090 Tusculum Ave, R-10; Cincinnati, OH 45226-1998.

endotoxin, and fungi. Further research into the degree and intensity of respiratory and dermal hazards in this industry, as well as resulting health effects, is recommended.

1. Introduction

Cannabis, commonly known as marijuana, is classified as a Schedule 1 substance under the United States Drug Enforcement Administration's Controlled Substance Act.[1] However, thirty-three states and the District of Columbia have legalized cannabis for medicinal use only or medicinal and recreational use. In 2017, the cannabis industry employed over 120,000 people with projections of nearly 300,000 workers by 2021.[2] Thus, the cannabis industry is made up of a substantial workforce that may be at-risk of unknown or overlooked workforce exposures, due to limited characterization of hazards in the industry.

In August 2016, National Institute for Occupational Safety and Health (NIOSH) representatives responded to a management and union request for a health hazard evaluation at a Minnesota medical cannabis cultivation and processing facility to characterize potential occupational exposures. Occupational safety and health (OSH) concerns in cannabis production, which are similar to those traditionally associated with agriculture, are often addressed by state organizations charged with overseeing their respective cannabis programs.[3–5] However, potential hazards including chemical and microbiological exposures unique to the cannabis industry have only recently been evaluated and require further characterization.[6–9] The purpose of this evaluation was to characterize occupational exposures and add to the existing body of OSH literature in the legal emerging U.S. cannabis harvesting and processing industry. Specifically, the authors aimed to characterize potential health hazards related to harvesting and processing of cannabis.

2. Materials and Methods

2.1 Facility Description

In response to the health hazard evaluation request, NIOSH representatives visited the facility in August 2016 and again in April 2017. The facility cultivated, harvested, and processed cannabis (*Cannabis sativa L. subsp sativa and Cannabis sativa L. subsp indica)* in both indoor and outdoor environments (Figure 1). Beginning with either seeds or mature donor plants grown indoors, production cannabis plants were moved throughout the facility during different life stages to maximize quality and growth. Maturing plants were moved either into indoor greenhouses or outdoor hoop houses (semicircular, fabric covered structures that allow sunlight penetration and air movement). Mature plants were then harvested in stages. Large branches (known as colas) containing multiple flowers were separated and transferred to a drying area away from the growing rooms. Destemming consisted of removing dried flowers from the cola with scissors or pruners. Dried flowers were then added to a grinder to produce a smaller, consistently sized product before being loaded into a decarboxylation oven (approximately 1.5 cubic feet) to convert delta-9 tetrahydrocannabinol acid (Δ9-THCA) into Δ9-THC. The decarboxylated product was placed into a carbon dioxide extraction system to yield an oil which was sent to final processing and product packaging.

2.2 Surface Wipe Sampling:

Eighteen (18) surface wipe samples for Δ9-THC were collected using 4 inch by 4 inch cotton twill wipes wetted with 3 milliliters of isopropyl alcohol. Where possible, a 100-square-centimer (100 cm^2) template was used to ensure consistent sampling technique. For each sample, the location and recent activities were noted. Surface wipe samples were analyzed by liquid chromatography and tandem mass spectrometry (LC-MSMS) [limit of detection = 4 nanograms (ng) per sample]. Where possible, a 2nd surface wipe was collected adjacent to the 1st for analysis of other phytocannabinoids (Δ9-THCA, cannabidiol and cannabinol) in addition to Δ9-THC, by high performance liquid chromatography with diode-array detection (HPLC-DAD) (limit of detection = 2,000 ng per sample). This method was modified from HPLC from the one used in a previously published manuscript.[10] The Δ9-THC only method is an established method in accordance with International Organization for Standardization 17025 requirements that has been internally developed by an American Industrial Hygiene Association accredited contract laboratory. Direct comparison of results from LC-MSMS (Δ9-THC only) and HPLC-DAD (four cannabinoid) results is not possible because contamination across surfaces was often not equally distributed.

2.3 Environmental and Personal Air Sampling

Volatile Organic Compounds—In August 2016, evacuated canisters (450 milliliter) with restricted flow controllers (6 hour, 15 minute, or instantaneous sample duration) were deployed to collect air samples for analysis of VOCs by gas chromatograph/mass spectrometer (GCMS). The method was modified to include a pre-concentrator, as well as the addition of diacetyl, and 2,3-pentanedione to VOCs specifically measured.[11] In addition to evacuated canisters, personal and area sample collection was undertaken to specifically target diacetyl and 2,3-pentanedione according to Occupational Safety and Health Administration (OSHA) methods 1013 and 1016.[12–13] The method was modified from the original gas chromatograph/mass spectrometer with flame ionization detector (GCMS-FID) to gas chromatograph/mass spectrometer operated in selected ion monitoring mode (GCMS-SIM) to increase the sensitivity of the method.[14] Thermal desorption tubes (NIOSH Method 2549) were also sampled to further characterize VOCs in the environment.[15]

Bioaerosols—Endotoxin personal and area aerosol samples were collected during the first site visit only. Personal full shift samples were collected during the entire work shift on 4 employees over 2 days (n=8). Area samples were collected in various locations throughout the facility including in the vegetation room (n=2), clone room (n=2), greenhouse 1 (n=11), greenhouse 2 (n=1), hoophouse C (n=2), hoophouse B (n=1), loading dock (n=1), and the breakroom (n=1). The personal and area samples were taken at an air flow rate of 2 liters per minute onto three-piece 37-millimeter closed-face cassettes preloaded with 0.45-micrometer-pore-size endotoxin-free polycarbonate filter and analyzed for endotoxin content with the kinetic-chromogenic procedure using the limulus amebocyte lysate assay (KC-LAL Assay) with a limit of detection of 0.5 endotoxin units (EU) (was 0.053 ng Endotoxin).[16]

Full-shift, personal samples (n=12) and area aerosol samples (n=25) were collected for the analysis of fungal community composition. The NIOSH two-stage BC251 bioaerosol

sampler was used to sample fungal aerosols for approximately 8 hours at an air flow rate of 2 liters per minute as previously described.[6,8] In August 2016, full-shift personal air samples were collected from 4 employees over 2 days (n=8), and area sampling was undertaken (n=11) in the same locations as for the endotoxin analysis with hoophouse samples representing outdoor grow exposures and greenhouse samples representing indoor grown exposures. In April 2017, personal full-shift sampling was undertaken with 2 employees over 2 days (n=4) and area sampling in the same 7 locations as previously over two days (n=14). The composition of fungi in personal and area samples collected at the facility was characterized using Internal Transcribed Spacer region sequencing. The extraction, primers, and sequencing instrument and process are described in a previous study of bioaerosol exposures at a Washington State Cannabis production facility.[6]

3. Results

Environmental THC Contamination

Of the 18 surface wipe samples analyzed by LCMS-MS (Δ9-THC, only), 15 (83%) had detectable amounts of Δ9-THC, and varied from below the limit of detection to 53,000 nanograms per 100 square centimeters (ng/100 cm^2) as seen in Table I. The highest concentrations of Δ9-THC were near the decarboxylation oven for both the LCMS-MS (53,000 ng per 100 cm^2) and the HPLC-DAD (17,000 ng per 100 cm^2). Samples with no detectable Δ9-THC were all collected in the breezeway area where minimal plant or cannabis products were observed.

For surface wipe samples analyzed for four cannabinoids by HPLC-DAD, results varied through the facility, with Δ9-THCA typically higher in comparison to the Δ9-THC (Table I). For this method, 4 of the 18 (22%) samples were positive for Δ9-THC, 8 (44%) for Δ9-THCA, 3 (17%) for cannabidiol and 2 (11%) for cannabinol.

While not directly comparable, the LCMS-MS (Δ9-THC only) method detected Δ9-THC in all but one sample location that the adjacent HPLC-DAD method (four cannabinoids) sample also had detectable Δ9-THC or Δ9-THCA concentrations. However, there were seven sample locations where the HPLC-DAD method did not detect either Δ9-THC or Δ9-THCA, but the LCMS-MS (Δ9-THC only) method had detectable Δ9-THC concentrations.

Airborne VOCs

In August 2016, VOC screening (evacuated canister) area samples revealed low-levels of diacetyl [range: 1.6−23 parts per billion (ppb)] and 2,3-pentanedione (range: not detected–9.3 ppb). During the April 2017 visit, evacuated canister personal sampling focused on the decarboxylation task to further investigate the elevated levels observed in the 2016 area samples. NIOSH has set a recommended exposure limit (REL) for diacetyl of 5 ppb and 2,3-pentanedione of 9.3 ppb, both as a time-weighted average for up to 8 hours per day during a 40 hour work week.[17] Diacetyl and 2,3-pentanedione were highest near the decarboxylation oven. Summary environmental area air sampling data for diacetyl and 2,3-pentanedione are presented in Table II.

Diacetyl or 2,3-pentanedione exposures measured during April 2017 were all below the NIOSH RELs. Breathing zone sampling for diacetyl and 2,3-pentanedione using the OSHA method ranged from 0.36–0.51 ppb with the three detectable sample concentrations all between the minimum detectable concentration (0.29 ppb) and the minimum quantifiable concentration (1.07 ppb). All OSHA method area air samples (N=7) were below detection limits except one sample for diacetyl near the decarboxylation oven that was between the minimum detectable concentration (0.30 ppb) and the minimum quantifiable concentration (1.03 ppb).

Personal evacuated canister samples, collected side by side with the OSHA method samples, did not detect diacetyl (minimum detectable concentration = 1.2 ppb). Two personal evacuated canister samples (both security personnel) measured trace amounts of 2,3-pentanedione (2.4 and 4.2 ppb) with both samples being between the minimum detectable concentration (2.2 ppb) and minimum quantifiable concentration (10 ppb). Four of six task-based evacuated canister samples (15 minute sample duration) collected during decarboxylation measured diacetyl, but only one sample (21 ppb) was above the minimum quantifiable concentration (7.6 ppb). Two of these task-based samples also measured 2,3-pentanedione (3.9 and 25 ppb) during decarboxylation (minimum quantifiable concentration = 11 ppb). Neither diacetyl nor 2,3-pentanedione was identified in any thermal desorption tube sample.

Full-shift endotoxin concentrations were all below the occupational exposure limit (OEL) of 90 endotoxin units per cubic meter (EU/m^3), which is recommended by the Dutch Expert Committee on Occupational Safety.[18] No United States OELs for endotoxin have been established. Personal, full-shift endotoxin air sample concentrations for cultivators were lower (5.4 and 15 EU/m^3) on day one when compared to day two (62 and 85 EU/m^3), which differed only in job tasks by a 45 minute grinding task on day two. However, these results approached the Dutch recommended OEL.

The Internal Transcribed Spacer region sequencing analysis of the 2016 site visit samples resulted in the identification of 569 sequences, clustered into 137 operational taxonomic units and 806 sequences clustered into 131 operational taxonomic units in samples derived from the 2017 site visit. The phylum Basidiomycota (56%) displayed the highest relative abundance in personal and area samples during the first site visit and the Agaricomycetes (30%) and Wallemiomycetes (22%) were the most prevalent fungal classes (Figure 2A). The phylum Ascomycota were also prevalent in samples accounting for 31% of identified sequences, and primarily consisted of fungi from the class Dothideomycetes (26%; Figure 2A). For sampling in April 2017, there was a shift in the predominant fungal taxa and the classes Cystobasidiomycetes, Ustilaginomycetes, and Wallemiomycetes were not identified during the second visit (Figure 2C). The most common taxa identified in 2016 included *Wallemia* spp, (22%), *Epicoccum nigrum* (8%), *Ganoderma applanatum* (7%), *Cladosporium cladosporioides* (7%), and *Cladosporium sphaerospermum* (5%) (Figure 2B), while in April 2017, the most common taxa were *Irpex lacteus* (10%), *Bjerkandera adusta* (7%), and *Cerrena unicolor* (3%) (Figure 2D). There was a shift in the dominant fungal classes in personal and area samples. Wallemiomycetes had a higher abundance in personal air samples (38%), while Agaricomycetes was higher in area samples (49%; Figure 2A).

Plant-derived sequences were also identified and accounted for 37% of all second site visit sequences and included *Cannabis sativa* and other regionally prevalent plant species (Figure 2D). Plant sequences primarily derived from *Cannabis sativa* were also identified and accounted for 80% of all sequences identified in personal air samples.

4. Discussion

Despite the majority of the facility's production area working with raw cannabis where one would expect to have higher concentrations of the unconverted phytocannabinoid Δ9-THCA than Δ9-THC, 15 out of 18 (83%) Δ9-THC only method samples had detectable concentrations of Δ9-THC. Even though not directly comparable because sampling was conducted side-by side, the Δ9-THC only method detected Δ9-THC in all but one sample that the four cannabinoid sample detected Δ9-THC or Δ9-THCA. In contrast, there were six paired samples where the four cannabinoid method did not detect any cannabinoid levels but the corresponding Δ9-THC only method had detectable levels of Δ9-THC. Because raw cannabis contains Δ9-THC and the Δ9-THC only method has a much lower limit of detection compared to the four cannabinoid method, these results suggest that the Δ9-THC only method can be an effective screening tool used in the cannabis industry to identify contaminated areas. These results also support the use of personal protective equipment, such as gloves, when handling cannabis or working in a cannabis cultivation/processing area, as well as practice of good personal hygiene and the introduction of cleaning schedules to reduce accumulation and exposure of workers to THC.

Even though the surface wipe samples for Δ9-THC only and the surface wipes for analysis of four cannabinoids were collected adjacent to one another, equal distribution of cannabinoids across both wipe sample areas cannot be assumed and therefore results cannot be compared directly. However, a comparison can be made for the results within the multiple cannabinoid method. For samples with detectable concentrations using the four cannabinoid method, Δ9-THCA concentrations were higher than Δ9-THC for every surface wipe sample except for one sample collected near the decarboxylation oven. These results suggest that Δ9-THCA surface contamination is greater than Δ9-THC when working with raw cannabis. The only sample in contradiction to this trend was collected near the decarboxylation oven. The oven converts Δ9-THCA into Δ9-THC, which may explain the higher Δ9-THC in this sample. Surface wipe samples detected cannabidiol and cannabinol less frequently than Δ9-THCA and Δ9-THC which may be an artifact of the cannabis strains being processed during sampling or an inability of the sampling method to detect cannabidiol and cannabinol at low levels. Chronic exposure to first hand cannabis smoke has been associated with social anxiety disorder, depressive disorders, psychosis, and respiratory symptoms; however, prior studies have primarily evaluated effects from inhalational exposures, and research is limited on negative health outcomes associated with direct skin contact with Δ9-THC or Δ9-THCA.[19]

During the study, a "partially validated" evacuated canister sampling method was used to screen for VOCs, and in August 2018, the evacuated canister sampling method became a fully validated method.[11,15] VOC screening was performed in both 2016 and 2017 and due to the detection of the potentially hazardous chemicals (diacetyl and 2,3-pentanedione),

a more rigorous follow-up sampling was undertaken in 2017 using the paired evacuated canister and OSHA method sampling (1013 and 1016). While the evacuated canister method yielded higher diacetyl and 2,3-pentanedione concentrations when compared to the corresponding OSHA method concentrations, the OSHA method is the standard regulatory method. For this reason, recommendations were based on the OSHA method results which were all below the NIOSH REL, as well as the short-term exposure limit of 25 ppb for diacetyl and 31 ppb for 2,3-pentanedione.[17] The highest detected level for diacetyl (21 and 23 ppb) and 2,3-pentanedione (25 ppb) were all observed by the evacuated canister method during decarboxylation tasks indicating that decarboxylation is the main source of the chemicals. The OSHA method results for all three cultivators were between the minimum detectable concentration and the minimum quantifiable concentration. This confirms that diacetyl was present but at low concentrations. These concentrations were at or near the analytical limits of the respective sampling methods which may explain the variable results for both diacetyl and 2,3-pentanedione.

Diacetyl and its substitute, 2,3-pentanedione, are widely used in the flavoring industry. Exposure to these chemicals has been shown to cause decreased lung function and serious respiratory disease, including obliterative bronchiolitis.[17] Obliterative bronchiolitis, also known as bronchiolitis obliterans, is an irreversible lung disease characterized by scarring in the bronchioles. Occupational exposures to airborne diacetyl and 2,3-pentanedione have also been identified in other industries. Bailey et al. identified six employees in a coffee processing facility with suspect obliterative bronchiolitis and five employees with work-related asthma associated with high exposures to diacetyl and 2,3-pentanedione.[20] Further characterization of potential exposure to these chemicals in cannabis processing facilities is warranted to prevent potential adverse respiratory outcomes.

Exposure to organic dust and high concentrations of endotoxin causes respiratory inflammation, respiratory symptoms, and declinations in lung function.[21] There is variable evidence about the health effects associated with exposure to low endotoxin concentrations (less than 100 EU/m^3), but it has been reported that levels as low as 45 EU/m^3 may cause acute airflow obstruction, mucous membrane irritation, chest tightness, cough, shortness of breath, fever and wheezing.[22] In this evaluation, endotoxin levels spiked during a short grinding task. As the cannabis industry continues to expand, the scale of these grinding operations may increase, resulting in higher concentration exposures to organic dust and endotoxin. Some studies have suggested that high endotoxin exposures may protect individuals from atopic sensitization.[23] Workers in the hemp industry, an industry thought to have similar exposures to the cannabis industry, have been shown to be exposed to endotoxin concentrations that exceed the Dutch OEL of 90 EU/m^3.[18] In one study, Fishwick and colleagues showed that the mean levels of inhalable endotoxin in the breathing zone of hemp fiber production workers were substantially higher than the Dutch OEL.[24] Work related tasks such as sweeping were work practices that resulted in the highest concentrations of endotoxin.[25] Hemp dust exposure has also been shown in previous European studies to result in work-related respiratory symptoms in hemp workers including abnormalities of lung function, chronic cough, dyspnea, byssinosis, as well as an increased incidence of skin test reactivity to hemp extracts.[25–29]

Internal Transcribed Spacer region sequencing revealed fungal taxa commonly detected in occupational environments.[30] Basidiomycota and Agaricomycetes were the most frequently identified fungal sequences in general area samples collected at the Minnesota facility, accounting for 20% of all fungal sequences. This includes Basidiomycota genera that form basidiocarps (e.g. mushrooms) that breakdown wood.[31] Agaricomycetes was the most prevalent fungal class captured in a recent survey of a cannabis facility in the state of Washington.[6] In contrast, personal air sampling of workers conducting harvesting and processing tasks was dominated by the Basidiomycota genus *Wallemia*. Previous studies that have assessed exposure to fungi during cannabis processing or harvesting applications have identified the cannabis plant pathogen *Botrytis cinerea*.[6] In this evaluation, *Botrytis cinerea* only accounted for 0.72% and 1.04% of fungal sequences identified during the first and second site visits, respectively.

Similar to this evaluation, other studies utilizing next generation sequencing have characterized the cannabis mycobiome that includes a variety of pathogenic and toxigenic *Aspergillus* and *Penicillium* species.[32–33] The results derived from the current study suggest that *Wallemia* species were either growing on processed cannabis or was present in the general vicinity of the worker. *Wallemia* is a common fungal contaminant in damp indoor and agricultural environments and personal exposure has been associated with respiratory morbidity such as hypersensitivity pneumonitis.[34–35] Additional analysis of cannabis processing environments in varying geographical environments is needed to provide a better understanding of fungal communities that workers could be exposed to during harvesting and processing activities.

This study adds valuable information to the literature with regards to potential occupational hazards related to cannabis but does have limitations that should be addressed in future research. Since a direct comparison between the two surface sampling methods could not be made, this study highlighted that care must be taken when selecting surface sampling methodology and that each method's advantages and disadvantages should be considered when designing exposure assessment protocols. Additionally, while traditional industrial hygiene exposure assessments deal with chemical measurements and OELs in the parts per million range, diacetyl and 2,3-pentanedione limits are measured and compared against OELs in the low ppb range. Characterizing exposures at these low ppb levels, which approach the analytical limits of detection, pose unique exposure assessment challenges.

5. Conclusions

To the authors' knowledge, this is the first published report of potential diacetyl and 2,3-pentanedione exposure in the cannabis industry, most notably during cannabis decarboxylation, albeit at levels significantly below the NIOSH REL and action level. Endotoxin exposure was elevated during grinding, indicating that this is a potentially high risk task. The results for fungal exposures, including the high relative abundance of the Basidiomycota genus *Wallemia*, indicate that bioaerosol exposure should also be considered when characterizing health hazards at cannabis operations, or when medically evaluating persons that work in the cannabis industry. Considering results were collected at only one

facility, further investigation is needed to better characterize the presence and concentrations of diacetyl and 2,3-pentanedione across this emerging industry.

REFERENCES

1. United States Drug Enforcement Administration. Drug Scheduling 2018. https://www.dea.gov/drug-scheduling. Accessed August 20, 2018.
2. Smith A The U.S. legal marijuana industry is booming. New York: CNN Money. https://money.cnn.com/2018/01/31/news/marijuana-state-of-the-union/. Accessed August 20, 2018.
3. Colorado Department of Public Health and Environment. Guide to worker safety and health in the marijuana industry. Denver, Colorado: Marijuana Occupational Health and Safety Work Group, Colorado Department of Public Health and Environment (CDPHE); 2017 https://www.colorado.gov/pacific/cdphe/marijuana-occupational-safety-and-health.
4. McDuffie HH, Dosman JA, Semchuk KM, Olenchock A, Senthilselvan A, eds. In: Agricultural health and safety: workplace, environment, sustainability. Boca Raton, FL: CRC press Inc; 1995.
5. Walters KM, Fisher GG, Tenney L. An overview of health and safety in the Colorado cannabis industry. Am J Ind Med. 2018;61(6):451–461. 10.1002/ajim.22834. [PubMed: 29537065]
6. Green BJ, Couch JR, Lemons AR, et al. Microbial hazards during harvesting and processing at an organic United States cannabis farm. J Occup Environ Hyg. 2018;15(5):430–440. [PubMed: 29370578]
7. Martyny JW, Serrano KA, Schaeffer JW, Van Dyke MV. Potential exposures associated with indoor marijuana growing operations. J Occup Environ Hyg. 2013;10(11):622–639. [PubMed: 24116667]
8. Couch J, Victory K, Lowe B, et al. Evaluation of potential hazards during harvesting and processing cannabis at an outdoor organic farm. National Institute for Occupational Safety and Health. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report 2015–0111-3271; 2017. http://www.cdc.gov/niosh/hhe/reports/pdfs/2015-0111-3271.pdf
9. Victory KR, Couch JR, Lowe BD, Green BJ. Notes from the Field: Occupational hazards associated with harvesting and processing cannabis — Washington, 2015–2016. MMWR Morb Mortal Wkly Rep. 2018;67(2):259–260. [PubMed: 29494573]
10. Ambach L, Penitschka F, Broillet A, Konig S, Weinmann W, Bernhard W. Simultaneous quantification of delta-9-THC, THC-acid A, CBN, and CBD in seized drugs using HPLC-DAD. Forensic Sci Int. 2014;243(Suppl C):107–111. [PubMed: 25005819]
11. LeBouf RF, Stefaniak AB, Virji MA. Validation of evacuated canisters for sampling volatile organic compounds in healthcare settings. J Environ Monit. 2012;14:977–983. [PubMed: 22322315]
12. Occupational Safety and Health Administration. Diacetyl and/or acetoin (OSHA Method 1013). Salt Lake City, UT: U.S. Department of Labor, Occupational Safety and Health Administration; 2017. https://www.osha.gov/dts/sltc/methods/validated/1013/1013.pdf.
13. Occupational Safety and Health Administration. 2,3-Pentanedione (OSHA Method 1016). Salt Lake City, UT: U.S. Department of Labor, Occupational Safety and Health Administration; 2017. https://www.osha.gov/dts/sltc/methods/validated/1016/1016.pdf.
14. LeBouf R, Simmons M. Increased sensitivity of OSHA method analysis of diacetyl and 2,3-pentanedione in air. J Occup Environ Hyg. 2017;14:343–348. [PubMed: 27792470]
15. National Institute for Occupational Safety and Health. NIOSH manual of analytical methods (NMAM). 5th ed. O'Connor PF, Ashley K, eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2018. DHHS (NIOSH) Publication No. 2014–151, http://www.cdc.gov/niosh/nmam.
16. Cambrex. Limulus Amebocyte Lysate (LAL), Kinetic-QCL. Catalog Number: 50–650U. Walkersville, MD; 2005.
17. McKernan LT, Niemeier RT, Kreiss K, et al. Criteria for a recommended standard: occupational exposure to diacetyl and 2,3-pentanedione. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational

Safety and Health, DHHS (NIOSH) Publication No. 2016–111; 2016. https://www.cdc.gov/niosh/docs/2016-111/pdfs/2016-111-all.pdf.

18. Dutch Expert Committee on Occupational Safety (DECOS). Endotoxins: health-based recommended occupational exposure limit. The Hague, Netherlands: Health Council of the Netherlands, Dutch Expert Committee on Occupational Standards; 2010. https://www.gezondheidsraad.nl/sites/default/files/201004OSH.pdf.
19. National Academy of Sciences, Engineering, and Medicine. The health effects of cannabis and cannabinoids: The current state of evidence and recommendations for research. Washington, DC: The National Academies Press; 2017, 10.17226/24625.
20. Bailey RL, Cox-Ganser JM, Duling MG, et al. Respiratory morbidity in a coffee processing workplace with sentinel obliterative bronchiolitis cases. Am J Ind Med. 2015;58(12):1235–1245. [PubMed: 26523478]
21. Farokhi A, Heederik D, Smit LAM. Respiratory health effects of exposure to low levels of airborne endotoxin-a systematic review. Environ Health. 2018;17(1): 14. [PubMed: 29422043]
22. Thorne PS, Duchaine C. 2007. Airborne bacteria and endotoxin. In: Hurst CJ, Crawford RL, Garland JL, Lipson DA, Mills AL, Stetzenbach LD, eds. Manual of environmental microbiology. 3rd ed. Washington, DC: American Society for Microbiology Press; 2007:989–1004.
23. Rylander R. Endotoxin and occupational airway disease. Curr Opin Allergy Clin Immunol. 2006;6(1):62–66. [PubMed: 16505614]
24. Fishwick D, Allan LJ, Wright A, Curran AD. Assessment of exposure to organic dust in a hemp processing plant. Ann Occup Hyg. 2001;45(7):577–583. [PubMed: 11583659]
25. Fishwick D, Allan LJ, Wright A, Barber CM, Curran AD. Respiratory symptoms, lung function and cell surface markers in a group of hemp fiber processors. Am J Ind Med. 2001;39(4):419–425. [PubMed: 11323792]
26. Zuskin E, Kanceljak B, Pokrajac D, Schachter EN, Witek TJ. Respiratory symptoms and lung function in hemp workers. Br J Ind Med. 1990;47(9):627–632. [PubMed: 2207034]
27. Valić F and Žusbrevekin E. Effects of hemp dust exposure on nonsmoking female textile workers. Arch Environ Health. 1971;23(5):359–364. [PubMed: 5133798]
28. Bouhuys A, Barbero A, Lindell SE, Roach SA, Schilling RSF. Byssinosis in hemp workers. Arch Environ Health. 1967;14(4):533–643. [PubMed: 6024478]
29. Zuskin E, Kanceljak B, Schachter EN et al. Immunological findings in hemp workers. Environ Res 1992; 59(2):350–361. [PubMed: 1464288]
30. Green BJ. Emerging insights into the occupational mycobiome. Curr Allergy Asthma Rep. 2018;18(11):62. [PubMed: 30259186]
31. Hibbett DS, Bauer R, Binder M, et al. Agaricomycetes. In: McLaughlin JD, Spatafora WJ eds. Systematics and Evolution: Part A. Springer Berlin Heidelberg, Berlin, Heidelberg; 2014:373–429.
32. McKernan K, Spangler J, Zhang L, Tadigotla V, Helbert Y, Foss T et al. Cannabis microbiome sequencing reveals several mycotoxic fungi native to dispensary grade Cannabis flowers. 2015;F1000 Res. 4:1422. 10.12688/f1000research.7507.2.
33. McKernan K, Spangler J, Helbert Y, Lynch RC, Devitt-Lee A, Zhang L et al. Metagenomic analysis of medicinal Cannabis samples; pathogenic bacteria, toxigenic fungi, and beneficial microbes grow in culture-based yeast and mold tests. 2016;F1000 Res. 5:2471. 10.12688/f1000research.9662.1.
34. Miller MR, Hankinson J, Brusasco V, et al. Indoor air quality in nonindustrial occupational environments. In: Rose VE, Cohrssen B, eds. Patty's industrial hygiene. 6th ed. 4 vol. New York: John Wiley & Sons, Inc; 2006.
35. Lappalainen S, Pasanen A-L, Reiman M, Kalliokoski P. Serum IgG Antibodies Against Wallemia sebi and Fusarium Species in Finnish Farmers. Ann Allergy Asthma Immunol. 1998;81(6):585–592. 10.1016/S1081-1206(10)62710-X. [PubMed: 9892031]

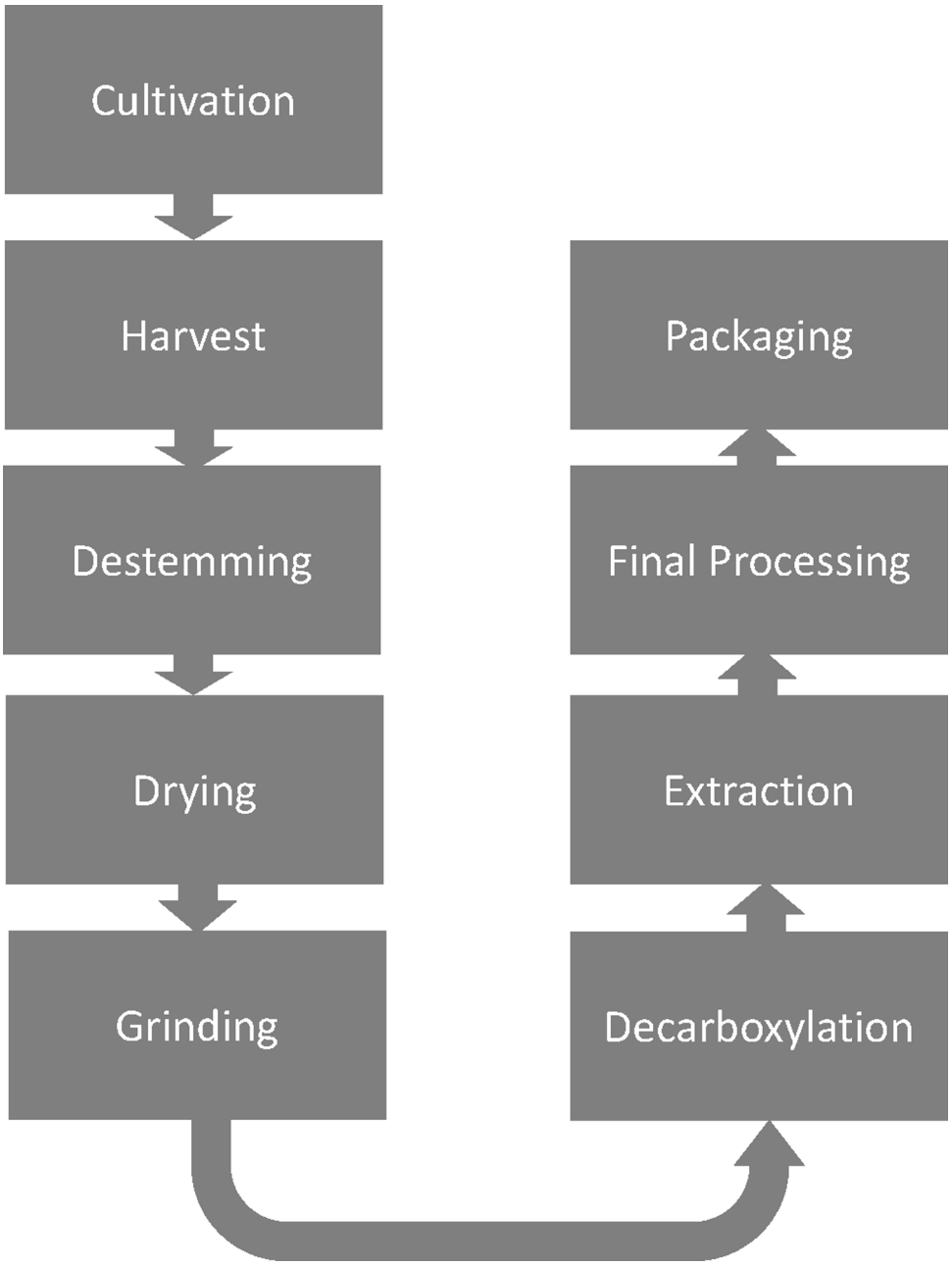

Figure 1.
Flow diagram of cannabis production at the facility

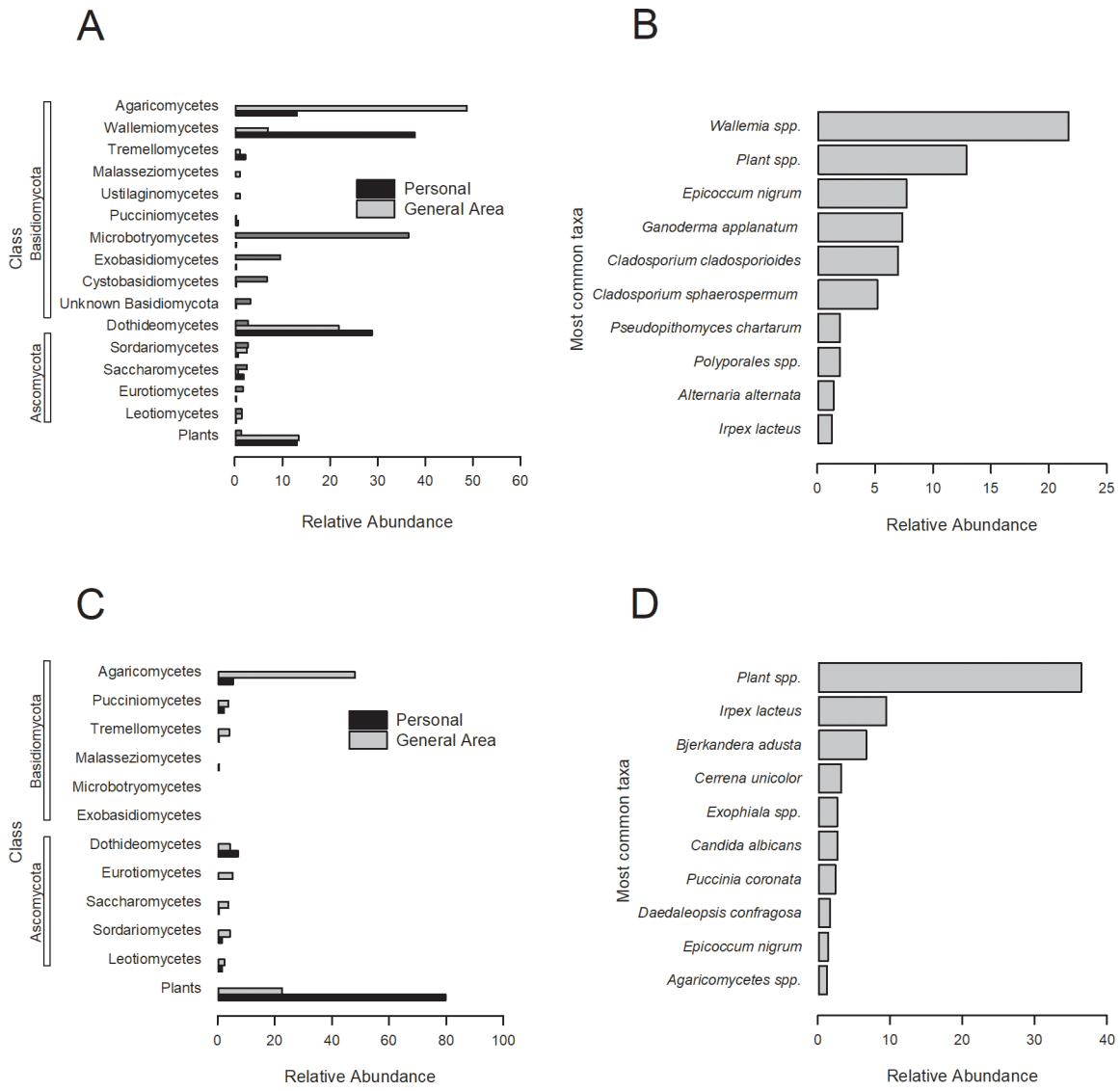

Figure 2.

Fungal relative abundance by class and sample type (A), and most common fungal taxa (B) for the August 2016 site visit and class and sample type (C), and most common fungal taxa (D) for the April 2017 site visit.

Table I.

Surface wipe sampling for cannabis compounds (ng per 100 cm^2) in August 2016

	Δ9-THC only	Four cannabinoid method			
Location	**Δ9-THC**	**Δ9-THC**	**Δ9-THCA**	**Cannabidiol**	**Cannabinol**
Loading dock					
Workbench	160	ND	ND	ND	ND
Workbench #2	20	ND	ND	ND	ND
Decarboxylation oven desk	53,000	17,000	ND	[3,700]	[2,100]
Vegetation room					
Table under white board	470	ND	[5,300]	ND	ND
Refrigerator door *	[7,8]	ND	ND	ND	ND
Greenhouse A door handle (Δ9-THC method only)	270	NA	NA	NA	NA
Greenhouse A door handle (Four cannabinoid method only)	NA	ND	[3,600]	ND	ND
Greenhouse A					
PVC pipe supporting plants *	450	ND	[4,100]	ND	ND
Pallet jack *	1,500	ND	9,500	ND	ND
Sink	590	[4,400]	34,000	ND	ND
Greenhouse B					
PVC pipe supporting plants *	110	ND	ND	ND	ND
PVC pipe under filter *	[14]	ND	ND	ND	ND
Breezeway					
Storage cabinet Workbench	ND	8,000	140,000	[5,200]	[6,400]
Workbench near greenhouse	ND	ND	ND	ND	ND
Mobile cart near back door	ND	ND	ND	ND	ND
Storage crate-center of room	14,000	15,000	62,000	[3,900]	ND
Breakroom					
Counter near coffeemaker	24	ND	ND	ND	ND
Counter in front of microwave	71	ND	[2,400]	ND	ND
Table	26	ND	ND	ND	ND

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

NA=Not available – insufficient space for 2nd sample

ND=Not detected

Values in brackets are between the limit of detection and limit of quantification. This means there is more uncertainty associated with the value.

Table II.

Summary area diacetyl and 2,3-pentanedione environmental air sample results in parts per billion

Location/Job Title	Samples (n)	Sample Time (Minutes)	Diacetyl	2,3-pentanedione
2016 Evacuated Canister Method				
Decarboxylation	1	Instantaneous	23	[4.4]
Decarboxylation	4	15	[1.2] – 6.7	ND – [1.7]
Grinding	2	15	[0.7 – 1.5]	ND
Greenhouse A	1	15	[3.0]	ND
Greenhouse A	2	360 – 480	[1.6] – 4.7	ND – [2.8]
Greenhouse B	2	360 – 480	3.0 – 3.7	ND
Vegetation room	1	15	5.8	5.1
Vegetation room	2	360 – 480	2.7 – 3.3	ND – [1.3]
Loading dock	2	360 – 480	[1.9] – 12	ND – 9.3
Outside grow	2	360 – 480	[1.6] – [2.1]	ND
2017 OSHA Method				
Grinding Room	1	345	ND	ND
Breezeway 1	2	298 – 373	ND	ND
Breezeway 2	2	338 – 375	ND	ND
Decarboxylation	2	550 – 561	ND – [0.26]	ND
NIOSH 8-hour time weighted average REL			5.0	9.3

ND = None detected

Values in brackets are between the minimum detectable concentrations and minimum quantifiable concentrations corresponding to more uncertainty associated with the value