Characterization of Occupational Exposure to Airborne Contaminants in an Indoor Cannabis Production Facility

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Abstract

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Background: While the cultivation and the use of cannabis continues to be illegal at the federal level in the United States, states and districts that have made medicinal and recreational use legal have seen dramatic increases in the number of workers being employed by cannabis-related companies. Little effort has been made to characterize and identify occupational hazards that workers may be facing in this industry, specifically airborne contaminants that may affect the human respiratory system. The purpose of this study was to quantify occupational exposures to Particulate Matter (PM) and Volatile Organic Compounds (VOCs) in various task zones (trim, pre-roll, grow and office) of an indoor cannabis facility in Washington State.

Methods: Full-shift (8-hour) area measurements of PM and VOCs were collected in each task zone over a 2-month study period at a single facility in Seattle. Measurement devices were placed near the employee's work area in order to attempt to estimate the exposure to the contaminants. The Dylos DC1100 Pro real-time optical particle counter with 4 size bins was used to measure particle number concentration (PNC), particle mass concentration (PMC) and cumulative size distribution of the particles in each task zone (n=8 per task). To quantify the VOC total terpene mass concentrations, a pump and sorbent tube set up was used in the trim (n=7), pre-roll (n=7), grow (n=8) and office (n=7) task areas. Sorbent tube samples were then analyzed for total terpene mass using GC/MS. Finally, correlations between PMC and total terpene mass concentrations were assessed.

Results: The mean PMCs were greater in task zones that required the employees to manipulate the cannabis plants and materials. The (PMC) for the trim task was 59 $\mu g/m^3$, pre-roll task was 50 $\mu g/m^3$, grow task was 43 $\mu g/m^3$ and for the referent office area was 19 $\mu g/m^3$. When comparing each task zone PMC to the office referent PMC, the trim task and the pre-roll task were significantly higher than the referent group, (p-values both <0.001). Results for the terpene samples indicated that the mean terpene mass concentration for the trim task was 34 mg/m^3, pre-roll task was 11 mg/m^3, grow task was 16 mg/m^3 and for the office referent space was 1.5 mg/m^3. When comparing each task zone total terpene mass concentration to the office space, only the trim task area was significantly different from the referent office space (p-value = 0.002). Correlations between PMC and total terpene mass concentrations for each task zone were weak based on spearman rank correlation tests.

Conclusions: Area concentrations of both PM and VOCs were greatest among the trim task area, followed by the pre-roll task and the grow task areas. This data can help inform the employer of the task zones where exposure to respiratory hazards are the highest, and where it may be beneficial to deploy control measures to reduce exposure. Results from the area measurements of PM and VOCs suggest that further research on employee personal exposure to similar airborne contaminants is needed to expand the knowledge base of exposures in this unique industry.

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Acronyms and Definitions

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
CDC	Centers for Disease Control and Prevention
DEA	Federal Drug Enforcement Agency
DEOHS	Department of Environmental and Occupational Health Sciences
Dylos	Dylos DC1100 Pro real-time particle monitor
GC/MS	Gas Chromatograph/Mass Spectrometry
GM	Geometric Mean
GSD	Geometric Standard Deviation
HEPA	High efficiency particulate air
IARC	International Agency for Research on Cancer
IQR	Interquartile Range
LLOD	Lower limit of detection
MMAD	Mass median aerodynamic equivalent diameter
NIOSH	National Institute of Occupational Safety and Health
NMAM	Manual of Analytic Methods
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PID	Photoionization detector
PNC	Particle number concentration
PMC	Particle mass concentration ($\mu g/m^3$)
PM	Particulate Matter
P-trak	TSI Inc. P-Trak Ultrafine Particle Counter Model 8525
RSD	Relative standard deviation
SD	Standard deviation
TLV	Threshold Limit Value
TWA_{8hour}	8-hour Time Weighted Average
UW	University of Washington
WEEL	Workplace Environmental Exposure Level

Introduction

History of cannabis and its legality

United States

The past several decades in the history of the United States have resulted in a number of monumental changes in the policies and restrictions that are in place regarding cannabis and cannabis-related products. In 1970, the Federal Drug Enforcement Agency (DEA) made the decision to define cannabis as a Schedule 1 substance under the US Controlled Substances Act. As the highest classification under federal law, this classification prohibits the use, possession, sale, cultivation, and transportation of cannabis and notes of its high abuse potential (Hasin, 2018; Mergel, 2016). Variation in public perception around the harmfulness of the plant/drug led to many states choosing to pass laws that would legalize the use of marijuana for medical purposes with the proper medical authorization (Hasin, 2018). California was the first state, in 1996, to decriminalize the medical use of cannabis with Proposition 215 (Health, 2011). Since this 1996 decision, 29 states have followed suit and have chosen to allow medical marijuana to be available to individuals whose terminal or debilitating illnesses may benefit from its use (Liquor Control Board Statement following Passage of Initiative 502, 2012).

The shift in public attitude towards the acceptability of cannabis and its products has led to the decline in the impression that regular cannabis use is risky among youth and adults. Adult trends in cannabis use in the U.S. mimic this outlook. In a survey that examined past-month cannabis use by participants 18 to 25 years old between the years 2002 and 2014, cannabis use has increased from 17% to 19.6% (Hasin, 2018). Similarly, trends of past-year use by adults were reported by the National Institute on Alcohol Abuse and Alcoholism. This organization indicated that from 2001-2002 the past-year prevalence of cannabis use among adults was 4.1% and has increased significantly to a past-year prevalence of 9.5% in the years 2012-2013 (Hasin, 2018). Currently, cannabis tops the list of most popular illicit drugs (past-month use) in the United States and is followed by prescription drug use for nonmedical purposes and prohibited drugs. Recreational use in the United States is the primary use with nearly ninety-percent of adult users using the drug in a recreational capacity and only ten-percent of adult users using the drug in a medical capacity (The National Academy of Sciences, 2017). Not only has the use of cannabis and its related products increased in the past few decades, but the potency of the products (THC content) has approximately doubled in the United States. Since the early 1990s, the average THC content in cannabis products has increased from 3.7% to 6.1%. Products that have higher levels of THC incorporated are

more likely to increase the potential risks, specifically the non-occupational risks, associated with its use (Hasin, 2018).

Following the beginning of medical marijuana legalization in 1996, Colorado and Washington State were the first to pass laws permitting recreational use of marijuana in 2012. These laws permit the legal sale and use of cannabis at the state-level without the need for medical jurisdiction or authorization (Hasin, 2018; McKenna, 2014). Today, six additional states (Alaska, Oregon, California, Nevada, Massachusetts, and Maine) and the District of Columbia have also deemed it acceptable to use marijuana in a recreational capacity (The National Academy of Sciences, 2017). A large discrepancy continues to exist between the state and federal statutes. Whereas individual states have chosen to legalize medical and recreational use of cannabis, federal law maintains that cannabis and its related products are illegal. Before 2009, individuals who were using marijuana and its related products in agreement with the state medical marijuana laws were still vulnerable to prosecution under federal law (Hasin, 2018). The first response to this discrepancy came from an issued memorandum in 2009 by the US Attorney General which instructed federal prosecutors to not prioritize prosecution of individuals who are compliant with their state medical marijuana laws (Hasin, 2018). Subsequent memoranda have been released to further clarify the policies of marijuana enforcement with the most recent coming from Attorney General, Jeff Sessions. The memorandum was released for all U.S. Attorneys entitled "Marijuana Enforcement" on January 4, 2018 which established that when deciding which marijuana activities to prosecute under previous established laws, that under the Department's "well-established general principles, previous nationwide guidance specific to marijuana enforcement is unnecessary and is rescinded, effective immediately" (Sessions, 2018). The memo stated that state-specific Attorneys General should investigate and prosecute under their own discretion in accordance with applicable laws, regulations and appropriations (Sessions, 2018).

The significant increase in cannabis/marijuana use in recent years has helped this unique industry emerge as a billion-dollar-a-year industry in several states. Colorado and Washington State are the current leaders in the growing and production of legal cannabis goods in the US. As of 2018, the cannabis industry is responsible for supporting up to approximately 125,000 to 160,000 full-time workers in the United States alone, with more growth expected in the upcoming years (Hasin, 2018; McVey, 2016). These estimates come from workers who are directly employed by cannabis businesses and does not take into account employment in businesses who may be providing additional materials (such as packaging) and services to cannabis businesses. McVey et al., reports that growth of this industry is expected to continue at 21% per year, and by the year 2022 the cannabis industry is expected to support as many as 340,000 full-time jobs, just over doubling the current industry levels (McVey, 2018). Although this industry may be challenged

by differing opinions and levels of the law, it appears that the industry has been successful in spite of pushback from some sections of society, and it will continue to be successful based on recent and estimated trends.

Washington State

Washington State has profited immensely from voting to legalize the medical and recreational use of cannabis and its products at the state level. The state's first initiate, Initiative 692, was approved in 1998 which allowed patients to be prescribed marijuana for medical purposes. In 2012, Washington State passed a second initiative, Initiative 502, which legalized the recreational use of cannabis and set a precedent for the growing, processing, and retailing activities, as well as the possession of marijuana. Recreational sales in Washington to the general public began on July 8th, 2014, but purchase and recreational use of cannabis products was restricted to those who were above the age of 21, and the amount to be purchased was limited to one ounce of usable marijuana (i.e. harvested flowers), sixteen ounces of edibles in the solid form, 72 ounces of edibles in the liquid form, and 7 grams of marijuana concentrates (L&C).

In order to obtain a license in the state of Washington, the facility must be separated into the type of work that will be done – marijuana producer, marijuana processor, or marijuana retailer. According to the Washington State Liquor and Cannabis Board, the majority of the marijuana producer facilities in Washington are designated as tier 2 or tier 3 facilities. The tier level indicates the size, in square footage, of dedicated plant canopy space allowed. For example, tier 1 facilities allow for two thousand square feet or less of dedicated plant canopy, tier 2 allows for two thousand to ten thousand square feet, while tier 3 allows for between ten thousand and thirty thousand square feet of dedicated canopy space. A marijuana processor license is described as a facility that processes, packages, and labels usable marijuana and marijuana-infused products for sale at wholesale to marijuana retailers. A marijuana retailer must only sell usable marijuana, infused products, concentrates or paraphernalia at a retail facility to adults twenty-one years of age or older. To date, Washington State has issued 516 retailer licenses and 1430 producer/processor licenses (Washington State Liquor and Cannabis Board, 2018).

Regulations and taxes imposed on the marijuana industry went into effect on July 1, 2015, and the state has profited immensely in terms of sales and excise taxes that have been collected. A 37% marijuana excise tax must be collected on products exclusively at the retail level. Tax revenue from this industry has been proposed to be directed towards education, health care, research and substance abuse prevention programs (Washington State Liquor and Cannabis Board, 2018). The Liquor and Cannabis Board

estimated that total sales in Fiscal Year (FY) 2017 reached $1.37 billion, while excise tax generated from legal marijuana sales and license fees reached $319 million (Washington State Liquor and Cannabis Board, 2017). For FY 2018, total sales in Washington State exceeded $3 billion and revenues brought in from taxes reached $367 million (Washington State Liquor and cannabis Board, 2018). Excise tax revenues from marijuana sales and fees now exceed revenues that are brought into the state from liquor taxes and licensing fees (Washington State Liquor and Cannabis Board, 2018).

Occupational hazards in the cannabis production industry

While this thesis focuses primarily on the broad characterization of occupational exposures to particulate matter and volatile organic compounds (VOCs) associated with different task zones, a few studies exist in the literature that evaluate exposures to particles and VOCs at a single task level. A study conducted by Martyny et al., in 2013 briefly discussed the presence of VOCs that are associated with the distinct smell of marijuana in illegal indoor marijuana grow operations. The study reported higher VOC levels in the grow rooms (50-100 ppb) versus the other areas of production and processing. The most prominent of these VOCs being alpha-pinene, beta-mycrene, beta-pinene, limonene and beta-caryophyllene (Doran et al., 2017; Martyny et al., 2013). In regard to particle exposures, the National Institute of Occupational Safety and Health (NIOSH) conducted a Health Hazard Evaluation (HHE) of a cannabis production facility where particle concentrations were collected in the air during a single grinding operation. Area airborne total particle concentrations that resulted from this operation averaged 3.4 mg/m^3, with a range of 0.01 to 20.5 mg/m^3 (Couch et al., 2018). It is necessary to point out that these results were measured during a single, 45-minute sampling period, and do not represent air concentrations or worker exposures for an entire 8-hour work shift.

Most health effects from long-term occupational exposures to cannabis are unknown, due to the tendency for most cannabis research studies to focus on non-occupational exposures and health effects (Victory, Couch, Lowe, & Green, 2018) However, potential occupational hazards posed by this industry include musculoskeletal risk factors from ergonomic issues, physical safety risks, exposure to elevated levels of carbon dioxide and carbon monoxide, THC, bacterial and fungal spores (Guide to Worker Safety and Health in the Marijuana Industry, 2017; Simpson, 2017; Injury and Illness in the emerging legal cannabis industry: Washington State Worker's Compensation Claims, July 2014 through September 2017, 2017). Workers employed in the Colorado cannabis industry reported a mild lack of concern for most physical workplace hazards on a Likert Scale (1-5). Ergonomic, physical safety and slips/trips/falls were rated with scores ranging from 2.22 to 2.8 (Walters, Fisher, & Tenney, 2018). The greatest area of concern for

musculoskeletal disorders were injuries to the hands, wrists and shoulders during prolonged harvesting and processing activities (Victory, Couch, Lowe, & Green, 2018). Workers also reported mild concern regarding air quality (mean Likert scale rating of 2.5) and respiratory issues from plant aerosols (median Likert scale rating of 2.3) (Walters, Fisher, & Tenney, 2018). Martyny et al found no elevated carbon monoxide levels even though combustion was used in carbon dioxide enrichment (Martyny, Serrano, Schaeffer, & Van Dyke, 2013). Previous studies of Δ9-THC have shown that exposure can cause acute and chronic health effects with recreational use. Δ9-THC is identified as the constituent that creates the intoxicated state of the user as it acts as a partial agonist for type-1 cannabinoid receptors. Other compounds of interest that are present in the plant include other cannabinoids and carboxylic precursors in addition to THC, terpenoids, flavonoids and nitrogenous compounds. When THC interacts with light or is combusted with heat, it is decarboxylated and can be converted into its psychoactive form (The National Academy of Sciences, 2017). Again, the long-term health implication of exposure to THC and associated cannabinoids in the occupational setting is unknown and needs to be further investigated (Victory, Couch, Lowe, & Green, 2018). It is known that in order for THC to become volatile and thus an inhalable hazard, it requires heat from burning the plant or steam vaporization. Therefore, THC is more likely to be found on surfaces, including plant particles, rather than as a vapor in the air. However, repeated trimming or handling of the intact plants gives rise to a greater potential that THC may be unintentionally absorbed or ingested (Doran, Deans, De Fillipis, Kostakis, & Howitt, 2017). Airborne levels of THC have been reported to be below the detection limit (0.001 $\mu g/cm^3$), while the geometric mean (GM) of surface wipe samples was found to be 0.0037 $\mu g/cm^2$ (Martyny, Serrano, Schaeffer, & Van Dyke, 2013).

Perhaps the greatest risk for respiratory illness from occupational exposure to cannabis comes from exposure to airborne bacterial and fungal spores. Indoor grow and production facilities must keep the environmental conditions within a specific range to maximize production. Typical requirements for growing cannabis in an indoor facility included keeping temperatures between 21°C and 32°C with a relative humidity level between 50% and 70% to encourage a moist growing environment (Martyny, Serrano, Schaeffer, & Van Dyke, 2013). Additionally, limited ventilation is introduced in order to reduce the level of aroma that is emitted from the facility. These characteristics can promote the growth of mold, fungi, bacteria and microorganisms that are commonly found on cannabis plants. Endotoxin, also known as lipopolysaccharides (LPS), are the major component of the outer cell membrane of a Gram-negative bacteria and have frequently been found to exist in occupational settings with high exposures to organic dusts and in environmental settings on plant surfaces (Gorbet & Sefton, 2005; Radon, 2006). Endotoxins are known to induce airway inflammation via inhalation and activation of alveolar macrophages and pro-

inflammatory cytokines (Radon, 2006). As a result, exposure to endotoxins have been found to increase the chances of developing organic dust toxic syndrome, chronic bronchitis, and asthma-like syndrome (Radon, 2006). Measurements of endotoxin concentrations during harvesting and processing of cannabis have been previously measured to be below the occupational safety recommendations that were set by the Dutch Expert Committee (Victory, Couch, Lowe, & Green, 2018). There is no U.S. standard for airborne endotoxin levels to compare concentration levels to (Victory, Couch, Lowe, & Green, 2018). *B. cinerea* is a well-characterized aeroallergen and plant pathogen of cannabis. Exposure to fungal spores can increase the risk for allergic and respiratory symptoms. Fungal spore levels reported by Martyny et al from sampling in illegal, indoor marijuana grow operations ranged from 72 cfu/m^3 to 4030 cfu/m^3. Comparing grow room levels of viable fungal spore colony counts to outdoor levels, the former was generally higher than the latter (Martyny, Serrano, Schaeffer, & Van Dyke, 2013).

Airborne Particulate Matter (PM) as an Occupational Health Hazard

Although research is limited in establishing a connection between the causative agents of health effects associated with exposure to airborne PM and organic dusts from cannabis, we can draw connections between the work that is done in typical agricultural settings and relate those to worker exposures in the cannabis industry. The workers in this field can be exposed to a wide range of particulate matter that makes up the composition of the airborne organic dusts released from their work with the plants. These dusts may include plant particles, glucans, viruses, bacteria, endotoxin, fungi, mycotoxins, pollen, insects, and compost (Davidson, et al., 2018). In addition to the organic dust, particles from other sources may be present including mineral dust from soil, pesticides and fertilizer. Inhalation is the main route of exposure to most airborne particles and organic dusts (Ramachandran, 2005). The mixture of these dusts can cause a combination of respiratory health hazards, and due to the complex nature of the mixture, can make it difficult to differentiate which aspect of the dust is causing such illness. Organic dust and particulate inhalation exposures are often associated with respiratory infections, irritation, inflammation, and allergic responses (Davidson, et al., 2018). The inhalation of fine particulates with aerodynamic equivalent diameters in the range of 5 to 10 micrometers are prone to enter and deposit in the upper airways and therefore cause these respiratory symptoms (Davidson, et al., 2018).

The ability of a particle to enter the human respiratory system beyond the nose and mouth is known as the inhalation efficiency. In the extrathoracic region, which is composed of the airways of the nose, mouth and throat, aerosols that are inhaled are typically deposited by inertial impaction. These particles are typically in the larger size fraction, greater than 10 micrometers. In the upper airways of the lung, the

thoracic region, smaller particles are able to penetrate and deposit by inertial impaction. Particles that have not yet impacted will move into the alveolar region which is comprised of alveolar ducts, alveolar sacs and the alveoli and is also where gas exchange of oxygen and carbon dioxide occurs. Particles between 0.5 and 2 micrometers deposit efficiently in the alveolar region. Particles that are typically greater than 10 micrometers are completely deposited in the extrathoracic region of the respiratory tract, while smaller particles are not completely deposited in the lower airways and a fraction are often exhaled (Ramachandran, 2005).

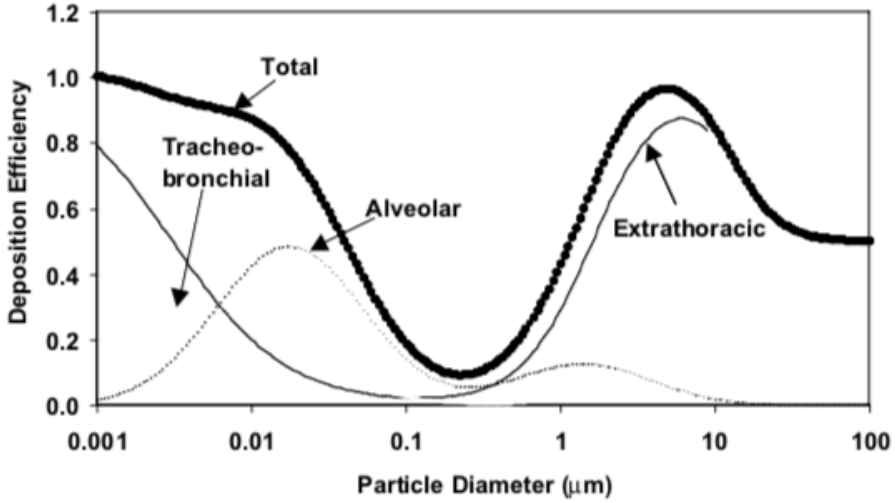

Figure 1. Deposition efficiency in the extrathoracic, tracheobronchial and alveolar regions of the respiratory tract - Ramachandran, G. (2005). *Occupational exposure assessment for air contaminants.* Boca Raton, FL: Taylor & Francis.

A series of historical studies conducted with hemp workers by Bouhuys et al. indicated a high prevalence of byssinosis and reduction of respiratory and pulmonary function between the beginning and end of each work shift (Bouhuys, 1969; Fishwick, Allan, Wright, Barber, & Curran, 2001; Nayak, Green, Sussman, & Beezhold, 2017). Additionally, workers in the hemp industry have demonstrated significantly higher rates of chronic symptoms of cough and phlegm, shortness of breath, and chest tightness compared to controls (Nayak, Green, Sussman, & Beezhold, 2017). Byssinosis may be caused by exposure to both bacterial and plant components of cannabis among workers in the industry. Byssinosis (occupational brown lung disease) is a broncho-constrictive disease that causes chest tightness, fever, headaches and muscle aches (Davidson, et al., 2018). This disease has been reported in hemp workers following the inhalation of organic dusts. Fishwick et al. reported high personal measurements of inhalable organic dust exposures that ranged from 10.4 mg/m^3 to 79.8 mg/m^3 among workers who process hemp products (Fishwick, Allan, Wright, Barber, & Curran, 2001). Organic dust toxic syndrome is common among dust-producing worker activities in the swine, poultry, and grain producing industries (Davidson, et al., 2018).

Occupational exposure from organic dusts derived from the cannabis plant can stimulate allergic reaction in both inhalation and dermal exposure scenarios. Workers that handle the plant *C. sativa* have reported both respiratory and dermal symptoms, which has shown a strong correlation to serological abnormalities among these workers. However, the underlying immunological mechanism has not yet been fully characterized, which poses a great limitation when attempting to pin down causality for this association (Nayak, Green, Sussman, & Beezhold, 2017).

VOCs as an Occupational Health Hazard

While it has been noted in the literature that exposure to VOCs presents a large number of health risks, it is the terpenes, a specific class of VOC, that are emitted when working with the cannabis plants that are thought to be potentially responsible for the respiratory and dermatological symptoms. Terpenes are compounds that are produced by plants and, in terms of cannabis, are responsible for the characteristic scent and taste (Fent, Durgam, West, Gibbins, & Smith, 2011; Couch, et al., 2018). While low levels of terpenes are unlikely to cause adverse health effects, they have the ability to react with oxidants found in indoor environments, such as ozone and hydroxyl radicals (Fent, Durgam, West, Gibbins, & Smith, 2011; Couch, et al., 2018). The reaction of terpenes with these oxidants can form highly oxidized species which are suspected to cause respiratory tract effects such as sensory irritation and airflow limitation (Couch, et al., 2018). Studies conducted by Eriksson et al. and Fent et al. have attempted to characterize terpene exposure among workers in Swedish joinery shops and police exposures working in a drug vault, respectively (Fent, Durgam, West, Gibbins, & Smith, 2011; Eriksson, et al., 1997). Both studies identified alpha-pinene, beta-pinene, and beta-carophyllene to be primary constituents of workplaces in which the sampling occurred. Eriksson et al. reported GM personal exposure to total terpenes that ranged from 19-123 mg/m^3, however this study took place in a Joinery Shop, which is not a typical agricultural setting (Eriksson, et al., 1997). Additionally, Fent et al. found relatively higher levels of beta-mycrene and limonene inside office areas compared to outdoor samples (Fent, Durgam, West, Gibbins, & Smith, 2011). More specific to the cannabis industry, NIOSH completed a Health Hazard Evaluation of a cannabis manufacturing facility where detection of multiple monoterpenes were found throughout the facility. However, no quantitative terpene or task-specific data were reported (Couch, et al., 2018).

Reported health symptoms from workers who were exposed to high levels of terpenes varied widely among study and specific workplace. The monoterpenes limonene, alpha-pinene and beta-pinene are known to be irritating to skin and mucous membranes and can cause allergic and nonallergic contact

dermatitis (Eriksson, et al., 1997). Terpene exposure has also been associated with respiratory effects among workers including decrease in lung function, airway inflammation and various nonspecific health symptoms such as sinus congestion, cough, runny nose, headache, eye irritation, skin rash, "memory fog" and burning eyes (Fent, Durgam, West, Gibbins, & Smith, 2011; Couch, et al., 2018; Eriksson, et al., 1997). Limonene is a fragrance terpene that is commonly used in cosmetics and cleaning products. D-limonene in its pure form is weakly allergenic, however because it is a prehapten, it can be transformed by air oxidation into a more allergenic compound - the most common being hydro peroxides (Som Nath, Liu, Green, & Reck, 2017). A retrospective study by Som Nath et al, found a high frequency of contact allergy to the fragrances linalool, D-limonene and their hydro peroxide oxidation compounds in a population of patients in a dermatology clinic at Duke University (Som Nath, Liu, Green, & Reck, 2017).

There is little regulation surrounding occupational exposure to VOCs, and terpenes in particular. Limonene is the only monoterpene that has an Occupational Exposure Level (OEL) of 170 mg/m^3 as an 8-hour Time-Weighted Average (TWA) which is a Workplace Environmental Exposure Level (WEEL) that is recommended by the American Industrial Hygiene Association (AIHA). This OEL is intended to prevent adverse effects to the liver (Fent, Durgam, West, Gibbins, & Smith, 2011). The International Agency for Research on Cancer (IARC) working group listed the 8-hour TWA for d-limonene in Sweden when performing their evaluation of the carcinogenicity to humans (IARC, 1999; National Board of Occupational Safety and Health, 1996). Sweden has an established OEL for total and individual monoterpene exposures set at 150 mg/m^3 (Eriksson, et al., 1997).

Description of an Indoor Production Facility

The process for producing cannabis in an indoor facility begins in a clone room, also known as the nursery. In this room, cuttings from mature donor plants, often referred to as "the mother", are removed to create the seedlings or clones. Therefore, the clones are new plants with the same characteristics as the donor plant (Couch, et al., 2018). The seedlings are each housed in an individual small pot, labeled with a unique identifier to differentiate which "mother" plants they came from. The clones are placed on tables below the grow lights where they are watered and hand-fertilized regularly. As the clones hit vegetative growth, the plants are replanted into larger pots and moved into an adjacent grow room. In the grow rooms, the life cycle of the plants is controlled by the light/dark conditions created by the grow lights and are determined and manipulated by the company themselves in order to push the plants from the vegetative into the flowering stage. Indoor growing operations can typically achieve three to four flowering cycles per year, while outdoor production is limited to a single grow cycle due to seasonality

and weather patterns. Once the plants reach full maturity and peak flowering, employees work to harvest the plants by removing the large stems and transferring the stems onto a hanging rack in a designated drying room (Couch, et al., 2018). Typically, the cannabis is dried for five to seven days and then destemmed, the process of hand removing dried flowers from the stem.

From the destemming process, the dried flowers are sorted and rated based on a combination of visual, olfactory, potency and terpene factors. The highest quality bud is hand trimmed to remove leaves and remaining stems and packaged as full, intact flower. In contrast, the lower quality bud is mechanically trimmed and crushed to create a coarse powder that will be transferred to the pre-rolling stage or can be extracted using solvents to create concentrates that are high in THC and other cannabinoid content that are sold as waxes, oils or used to infuse edibles. At the pre-roll stage, the coarse powder is sifted to further remove low quality flower and then finally loaded into rolled joint packaging.

Specific Aims

There are a limited number of studies in the current literature that have conducted sampling of occupational exposures to particulate matter and VOCs in cannabis production and processing facilities. Additionally, of the studies that are available, the exposure estimates are either qualitative in nature, or only focus on one aspect of the production process. Our study seeks to reduce this gap in knowledge by providing quantitative occupational exposure measurements of PM and VOCs, in each of the different task areas (trimming, pre-rolling/processing, growing and office) in an indoor cannabis production facility in Seattle, Washington.

The primary objective of this study is to conduct area measurements and characterize occupational PM and VOC (terpene) concentrations in the specific task zones of an indoor cannabis cultivation and processing workplace. The secondary purpose of this study is to compare the levels of PM concentrations to levels of total terpene mass concentrations across task zones. Establishing a relationship between PM concentrations and total terpene mass concentrations would be beneficial in understanding whether or not an individual airborne contaminant or a combination of PM and VOCs are contributing to negative health outcomes among the workers. The three specific aims of this research project are to:

Aim 1. Determine the differences in PM mass concentrations and size distributions among four specific task zones within an indoor cannabis production facility

Aim 1a. Measure and compare PM mass concentrations (PMC) and particle number concentrations (PNC) associated with the four task zones: trim, pre-roll, grow and office using a Dylos DC1100 real-time optical particle counter with 4 different size bins and the Ptrak Model 8525 Ultrafine Particle Counter.

Aim 1b. Quantify and compare the particle size distributions associated with the four specific task zones using mass fraction data from the Dylos DC1100 real-time optical particle counter with 4 different size bins.

Aim 2. Quantify and compare VOC total terpene mass concentrations, measured using sorbent tubes and GC/MS, associated with four specific task zones (trim, pre-roll, grow and office) within an indoor cannabis production facility.

Aim 3. Compare correlation between total PMC to total terpene mass concentrations among the four specific task zones.

The outcomes of the aims described above will help quantify and compare airborne contaminant concentrations and exposure potential in this unique and upcoming industry. Additionally, the data may provide useful insight into potential illness that may occur as a result of worker exposure and can thus provide a means to approach individual exposure assessment and intervention techniques.

Methods

Study Design

This research project is supported by funding through the National Institute of Occupational Safety and Health (NIOSH; Grant # T42 OH008433; U54 OH 007544) and by the National Institute of Environmental Health Sciences (NIEHS; Grant # P30ES007033). It is a part of a larger research study entitled "Respiratory Health and Indoor Air Quality in Washington's Cannabis Industry." The project is a pilot observational study that examines the current occupational exposures to airborne contaminants by workers who produce and grow cannabis. The study implemented the use of area sampling using real-time and integrated sampling methods and equipment specifically to measure particulate matter and terpenes in a single facility. Observations of employee's work activities were recorded on each day of sampling. The sampled facility, measurement methods, and data analysis methods are described in the proceeding sections.

Research Study Setting

All data collected for this research study was gathered from a single cannabis production facility located in Seattle, Washington. The facility was established in early 2011 initially to produce medicinal marijuana. By August of 2011, the company became the first permitted commercial cannabis production company in Washington State. With recreational, adult-use cannabis in the market as of 2014, the facility expanded to a larger warehouse setting in which this study was conducted. The facility houses the entire operation from cultivation to shipment and employs approximately 40 workers. Cannabis production expanded from growing solely outdoors to include large-scale indoor production that requires large amounts of energy usage (Mills, 2012). Indoor production allows the companies to better monitor and manage pest and disease outbreak among the plants, improve crop yield and control the growing process which is not as feasible in outdoor growing practices (Mills, 2012).

Data Collection & Field Work

Data collection for this study occurred in three separate campaigns, which included a preliminary collection day to ensure all data collection methods and use of equipment would be appropriate for follow-up measurements. The preliminary sampling day occurred in early October 2018 and acted as the study team's "mock run through" of the field work protocol (Appendix I). The proceeding sampling

campaigns occurred from December 3-14, 2018 and January 14-25, 2019. These campaigns each occurred over a consecutive two-week period in their corresponding month, with samples being collected during the entire work shift on the Monday and Friday work days for a total of four sampling days per campaign, 8 sampling days total. All the samples were collected during a typical day shift from 8:00 am until 4:30 pm, there were no regular night shift hours for workers at this facility. At the start of each sampling day, each piece of sampling equipment was set up in each of the four task zones that were chosen to best represent worker exposures to airborne contaminants. These locations within the facility included the trim area, the pre-roll area, the grow rooms and the office area (Figure 1). The trim, pre-roll and grow areas are distinct areas within the facility in which the highest concentrations of particulate matter and terpenes occur, as determined in our preliminary sampling day in October 2018. They are also the locations in which employees are present and completing their work for the majority of the work shift. It is important to note that in the main production space – which included the pre-roll task zone and some of the mechanical trim tasks – the facility had installed two high efficiency particulate air (HEPA) filters. These filters were the only examples of existing controls on-site which may affect the PM or VOC concentration levels. Due to budget and time constraints we wanted to focus our sampling efforts on areas in the indoor production facility in which high exposures may occur and where employees are present for more than a few minutes throughout their work day. To best represent worker exposures, sampling equipment was placed as close to the worker's task zones as possible without interrupting their daily tasks, and at breathing zone height.

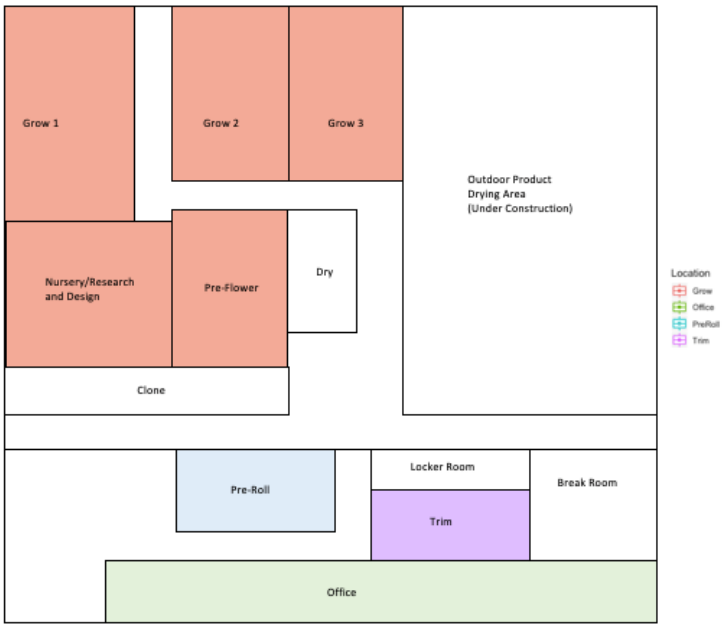

Figure 2. Layout of the indoor cannabis production facility in which sampling for this research study took place

Particulate Matter Sampling Devices

We employed the use of the Dylos DC1100 Pro (Dylos) optical particle counter devices to measure continuous particle count concentrations in each task zone. These devices pulled air at a flow rate of 0.06 ft^3/min (1699 cm^3/min) and were set up to log the aerosol concentration every 60 seconds. The Dylos samplers are designed to measure particles in four size bins of different aerodynamic diameters. Bin 1 (b_1) measured particles greater than 0.5 μm, bin 2 (b_2) measured particles greater than 1.0 μm, Bin 3 (b_3) captured particles greater than 2.5 μm in diameter and finally bin 4 (b_4) captured particles greater than 10 μm in diameter.

Figure II-1 in Appendix II provides a visual demonstration of the 8-hour colocation experiment that was conducted in an indoor setting to ensure that all four of the devices that were used during the sampling campaigns had similar PM responses. One limitation of utilizing the Dylos monitors as our continuous particle measuring instrument is that the monitors were not able to be calibrated before each sampling day. This is due to the fact that they were pre-calibrated by the manufacturer (and sent in annually to ensure proper calibration) and the instruction manual did not provide procedures to calibrate or check the zero readings of the devices. However, several studies have been conducted in the literature that indicate that these low-cost monitors have been reliably used and evaluated against more expensive and more sophisticated light scattering devices. Jones et al. evaluated the Dylos monitors in an agricultural setting and its correlation to the pDR-1200, an aerosol photometer (Jones, et al., 2016). Jones et al. used two methods when converting PNCs to PMCs produced from the Dylos monitors. In the first method, Jones et al. estimated particle mass concentrations using Equation 2 by assuming a unimodal particle size distribution and a density value of 1.45 g/cm^3 (Jones, et al., 2016). In the second method, a linear regression model was created based on 20% of the PNCs from the Dylos and PMC values for the pDR-1200 sample. The validated linear model was then used to convert the remaining 80% of the Dylos data to PMC. The outcomes from these instruments were found to be highly correlated with an R-squared value of 0.85 (Jones, et al., 2016). Additionally, a study conducted by Manikonda et al. found that the Dylos performed well in terms of accuracy and precision of the device when compared to well-characterized referent devices, the Grimm 1.109 (Grimm Technologies), APS 3321 (TSI Inc.) and the FMPS 3091 (TSI Inc.). The Dylos DC 1100 monitor demonstrated high correlations with all three of the referent instruments (R^2 values between 0.87 and 0.97) (Manikonda, Zikova, Hopke, & Ferro, 2016).

Four Dylos monitors were utilized on each unique sampling day, one monitor per each task zone. The monitors were synchronized to the correct date and time and data histories were cleared before each sampling day to avoid overloading the memory on the device. As mentioned previously, the Dylos

monitor was positioned as close to the breathing height and the work zone of the employees as possible, in each of the four task areas (trim, pre-roll, grow and office). The inlets of each of the samplers faced towards the work area. The monitors were turned on to begin collecting data at approximately 8:00 am and were turned off at the end of the work shift at approximately 4:30 pm.

In addition to the Dylos monitors, the study included the use of a TSI P-Trak Ultrafine Particle Counter, Model 8525, as a secondary measurement instrument to monitor for particles in the ultrafine range. The P-Trak detects and counts ultrafine particles which are defined as having a diameter less than 0.1 μm (100 nm). The P-Trak is a miniature version of a condensation nuclei counter (CNC). The particles that are detected with this type of instrument are so small, that they must first be saturated with a vapor of water or alcohol so that the vapor is able to condense onto the aerosol particles which causes the aerosols to become large enough in size that they are then able to be detected by light scattering techniques. An optical particle counter within the device will then produce a particle number concentration (Ramachandran, 2005).

Due to lack of access to multiple P-Trak devices, a single P-Trak was used during the study and was rotated around each of the four task zones on different sampling days. Therefore, the device would be used entirely in one task zone for a full shift of measurements, and then rotated to the next task zone for a full shift of measurement on the next sampling day. The P-Trak was programmed to log the particle number concentrations in the task zone every sixty seconds for the duration of the work shift. The P-Trak was positioned in the same location as the Dylos monitors.

Our initial study methods included an integrated pump and filter sampling technique which used a Teflon filter placed in an IOM sampler which is designed to sample particles that are in the inhalable range. However, upon gravimetric analysis in the lab, it was found that for many of the samples, improper handling or storage procedures caused the variation in the field blank pre- and post-weights to be unusually large. Therefore, the calculations for particle mass concentrations using the pump and filter setup were not reliable. The study team determined that the IOM samples would no longer be included in the methods and analysis for this research project.

Volatile Organic Compound & Terpene Sampling Devices

Integrated area air sampling for terpenes followed the NIOSH Manual of Analytic Methods (NMAM) 1552: Terpenes (Terpenes: Method 1552, 1996), with some modifications. Air samples for terpenes were collected near worker task areas, in the breathing zone, for a full shift, 8-hour sampling period. The

samples were collected on sorbent tubes composed of anasorb CSC Coconut Charcoal (SKC inc, P/N 226-09). SKC AirChek and PXCR personal sampling pumps were utilized to maintain a flow rate through the charcoal sorbent tube of approximately 200 mL/minute. The flow rate was calibrated for each personal sampling pump using a DryCal defender primary gas flow calibrator (SKC Inc.), with a representative "Calibration" sorbent tube sampler in line using tubing with a critical orifice in order to calibrate at a low flow rate. The ends of the sorbent tubes were scored and broken immediately before sampling began. Four sorbent tubes were labeled with a unique identifier for each task zone on each day of sampling. The flow rate for each sorbent tube set up was re-measured following each sample collection period with the loaded sorbent tube in-line. Pre and post-flow sample rates were averaged to get the average flow rate over the full-shift sampling and then multiplied by the sampling time in order to get the air volume for each sample. After collection, the sorbent tubes were capped with plastic caps and were wrapped in aluminum foil and stored at -20 °C until extraction occurred. Additionally, a field blank was created for each day of sampling.

Secondary analysis of VOCs in each task zone within the facility was monitored via a custom-built continuous reading monitor with photoionization detector (PID) sensor. With this device, a PID sensor is hooked up to a battery pack with an Arduino microcontroller and an SD card installed for data logging. The PID sensor will begin detecting VOCs (non-speciated) when power is turned on and will log a value onto the SD card or directly onto a computer every five seconds. The value that is logged is an arbitrary voltage number in analog-to-digital (ADC) units that represents the level of VOCs in that specific task zone. An ADC circuit converts the PID input voltage into an arbitrary digital response through the use of an integrator. Post-shift calibration of the voltage value using a standard curve that was produced experimentally in an exposure chamber is required in order to convert the VOC concentration into parts per million (isobutylene equivalents).

Similar to the set-up of the P-Trak Ultrafine Particle Counter, due to limited resources only a single VOC PID sensor was available for use in this study. Therefore, the sensor was placed in a single task area for the duration of a full shift of sampling and then rotated through the remaining three task areas on subsequent sampling days.

Daily Task Observations

In addition to the sampling methods described above, a member of the study team was responsible for visiting each of the four task areas where the samples were being collected every hour to record

observations. These observations focused on workers' job tasks that were being performed and daily activities through the full work shift.

Sample Analysis

Particulate Matter Sample Analysis

Following each day of sampling, the particle data that was logged on the Dylos DC1100 Pro instruments was downloaded using PuTTy software (beta 0.67) to an excel spreadsheet with a unique date identifier. Similarly, the P-Trak ultrafine particle data was downloaded onto a computer via the associated TrakPro ™ Data Analysis Software and saved into an Excel file.

Volatile Organic Compound Sample Analysis

In order to properly analyze the data that was produced by the VOC PID sensor, a standard calibration curve needed to be produced in a laboratory setting. In this experiment we calibrated the VOC PID sensor by filling the chamber with a known concentration of the calibration gas (isobutylene). The VOC PID sensor was placed inside an exposure calibration chamber in the Seto Lab at the University of Washington Health Sciences Building. The calibration chamber (~1 cubic foot in volume) was then charged with a known concentration of 23 ppm of isobutylene. Additionally, the chamber was supplied with dry air at a flow rate of 4 L/minute and contained a circulation fan to ensure the air was well mixed within the chamber. As the supply air is brought into the chamber via the pump system, the concentration of isobutylene will decay as a first order process. The equation (equation 1) which approximates this decay, assuming a well-mixed chamber is:

$$C = C_0 e^{-kt}, where$$

$$k = \frac{ventilation\ rate\ into\ the\ chamber}{chamber\ volume}$$

$$C_{0=}\ initial\ tracer\ concentration\ (isobutylene)$$

$$C = tracer\ concentration\ at\ any\ time, t$$

$$e = base\ of\ natural\ logarithms$$

Equation 1. Decay equation to calculate concentration at any given point in time

The decay equation was used to calculate the value of C at any given point in time in the decay process. The slope of the decay was examined to calculate the decay constant (k) was. From here, the decay

constant can be plugged into the first order equation above to determine what the actual concentration (C) is at any point in time. A calibration curve was created by plotting the instrument response versus the calculated concentration. Linear regression was used to calculate the slope of this relationship, and this slope value was used to convert the voltage response in ADC units that will be produced when the real-time sampling occurs into units of concentration of isobutylene (Appendix II, Figures II-2 through II-5).

The VOC PID Sensor was calibrated following the above procedure seven separate times. The relative standard deviation (RSD) of the slope of the calibration curves was 4%, therefore we used an average of the seven calibrations to determine the slope factor that would allow the linear regression to be solved to convert the ADC units into concentration units in parts per million (Appendix II, Table II-1). The upper quantification limit was calibrated at 23 ppm which corresponded to approximately 600 ADC units. The lower limit of detection (LLOD) was calculated to be 0.6 ppm, equivalent to approximately 15-16 ADC units. The LLOD was calculated based upon the lowest PID sensor value that was clearly distinguishable from background noise. An isobutylene concentration of zero ppm corresponded to a VOC PID Sensor reading of 12 +/- 2 ADC units.

Terpene Sample Analysis

The analysis of 21 terpenes followed NIOSH Manual of Analytic Methods (NMAM) 1552: Terpenes, with some modifications. Extraction was performed on air samples collected during the research study on sorbent tubes composed of coconut shell charcoal. Each sorbent tube's front and back segments were extracted in separate 4 mL ashed glass vials sealed with PTFE/Silicone septas. 2 mL of dichloromethane spiked with 200 ng/mL of internal standards, d^6 -β-myrcene and d^3-α-terpineol, is added to each vial through the septa for extraction. The sorbent samples were extracted for two hours on a shaker table. Approximately 0.5 mL of each extract was then transferred to a 2 mL autosampler vial and capped with PTFE/Silicone septa. Quality assurance samples consisting of sorbent spiked with 500 ng of each of the 21 terpenes as well as method blanks, consisting of only sorbent, were extracted with each batch. Terpenes were analyzed by gas chromatography-mass spectrometry (GC/MS) utilizing an Agilent Technologies 7890A GC and 5977A MSD. 2 µL of sample were injected into a 250° C splitless inlet. Chromatographic separation of terpenes was achieved with a Restek RTX-5ms column (30m, 0.25 mm ID) with an initial oven temperature of 40° C, held for 2.25 minutes, then ramping at 20° C per minute to a maximum temperature of 290° C. The flow of the helium carrier gas was 1.1 mL/minute. Terpenes were detected by mass spectrometry (MS), scanning from *m/z* 30 to 250. Terpene concentrations were determined by analyzing a set of six calibrants over the range of 25 ng/mL to 1000 ng/mL. Calibration

curves were calculated by linear regression ($r^2 > 0.99$) and applied to calculate analyte concentrations in environmental samples using Agilent Technologies MassHunter Quantitative Analysis Software.

Appendix II, Table II-2 lists each of the individual twenty-one terpenes that were analyzed by GC/MS and the corresponding quality control data averaged from both the December and January sampling campaigns including average spike recovery percentage, recovery relative standard deviation (RSD), and limit of detection (LOD) values. The average batch recovery percentage from both sampling campaigns was utilized to adjust the raw terpene masses to corrected values.

Data Analysis

Particulate Matter Data

All particulate data produced from the Dylos DC1100 Pro and P-Trak Ultrafine Particulate Counter devices were imported into the RStudio statistical package from their respective excel spreadsheets to be analyzed.

Due to the particle counting specifications of the Dylos devices, it was necessary to adjust the raw output from each sampling day in order to get the particle count concentrations (PNC) for each separate bin. This is due to the fact that the Dylos device logs the data in a way that the first cut point consists of data >0.5 μm, the second cut point has data >1.0 μm, the third cut point is all particles >2.5 μm, and the final cut point contains all particles >10 μm. Therefore, to get the PNC values for each individual bin, the average value from the raw output of the first cut point, must be subtracted from the average value from the raw output of the second cut point, continuing until the final bin, which records PNC >10 μm remains and does not need to be adjusted.

At this point, the PNC values in each of the four bins are in units of count/0.01ft^3 and were converted into units of count/m^3 by multiplying the average bin value by a conversion factor of 35.3147 ft^3/m^3 and by an additional factor of 100 to convert from 0.01 ft^3 to 1 ft^3. From this step, PNCs were further converted from count per cubic meter to microgram per cubic meter by using a consistent aerosol density value of 1.5 grams per cubic meter (converted to micrograms per cubic meter) and equation 2. The aerosol density value was chosen based on literature review of particulate matter monitoring in various agricultural settings where similar processing and plant matter were being manipulated and aerosolized (Cambra-Lopez, 2011; Lee, et al., 2006; Parnell, Jones, Rutherford, & Goforth, 1986). The midpoint of each bin on the log-scale was used due to the expectation that the data be log-normally distributed, except for the

fourth bin where, by convention, the lower cut size of 10 µm was used (d_1 = 0.71 µm, d_2 = 1.58 µm, d_3 = 5.00 µm, and d_4 = 10.00 µm) (Blanco, et al., 2018). Using equation 2 and the aforementioned variables, each bin's PNC was converted into particle mass concentrations (PMCs). To get total PMC for each location and each sampling day, all four bin's PMCs were summed together.

$$PMC_{Total} = \sum_{b=1}^{4} \quad (PNC_b \; x \; \frac{\pi}{6} \; x \; d_b^3 \; x \; \rho)$$

$$PMC_{Total} = \sum_{b=1}^{4} \quad \left(\left(\frac{count}{0.01 \; ft^3} * 100 * \frac{35.3247 ft^3}{m^3} PNC_b \right) * \left(\frac{\pi}{6} \right) * \left(\frac{bin \; diameter \; \left(\frac{\mu m}{count} \right)}{10^6 m} \right)^3 \right.$$

$$\left. * \left(assumed \; density \; \left(\frac{g}{cm^3} \right) * \frac{10^6 \mu g}{g} * \frac{10^6 cm^3}{m^3} \right) \right)$$

Equation 2. Calculating PMC from PNC

The P-Trak Ultrafine Particle Counter logged and provided particle output in units of particles per cubic centimeter, therefore no additional conversions were necessary for this data.

Volatile Organic Compound and Terpene Data

Results from the GC/MS sample analysis of the sorbent tubes provided the mass per sample for twenty-one individual terpenes. In order to calculate mass concentrations of total terpenes from each sample, the batch recovery percentage from the analysis was applied to the uncorrected mass from both the front and back end of each sorbent tube for each individual terpene to get a total corrected mass in nanograms (ng). Corrected mass was converted from nanograms to micrograms and then divided by volume of air that was sampled for each individual sampling pump to end with an air concentration in micrograms per cubic meter for each of the 21 individual terpenes. Finally, each terpene-specific mass concentration was added together for each sample to get total terpene mass concentration (µg/m^3).

Following the sorbent tube sample analysis by GC/MS, data for the 21 individual terpenes were reviewed for errors. If an error was present, a flag was assigned to the terpene-specific values that corresponded to the particular error. Descriptions regarding the flagging variables can be found in Table 3 of Appendix II.

Statistical Analyses based on Specific Aims

Aim 1 of this research study assessed the differences in particle number concentrations, particle mass concentrations and size distributions among the four specific task zones within the research facility. Summary statistics for PNC and PMC among each of the task zones were calculated, including sample sizes, arithmetic means, medians, standard deviations, and interquartile ranges (25^{th} percentile – 75^{th} percentile). PNC and PMC data were assessed for log-normality using histograms and the Shapiro-Wilk normality test. Results of these analyses can be found in Appendix II: Table II-4 and Figures II-6 through II-11. Additionally, PMCs from the Dylos instrument and PNCs from the P-Trak instrument were plotted in boxplots in order to observe inter- and intra-task zone variability. To further examine the inter-task zone variation of PMC and PNC, the Mann-Whitney U Test was used to compare the distributions of each of two locations. The Mann-Whitney U Test assesses the differences in the ranks of the values in the distributions of two independent groups and is typically used when sample sizes are small and/or when the data do not fit a normal distribution. For this study, it was of interest to compare the trim, pre-roll, and grow task zones each to the reference location of the office area, to see if there is a statistically significant difference between the PMC and PNC values of each task zone as compared to the referent group. Part b of Aim 1 focused on quantifying and comparing the particle size distributions associated with the four specific task zones using mass fraction data from the Dylos DC1100 particle counter with 4 different size bins. Additionally, for each task zone a log-probability plot was generated, and the size distributions were summarized by using the mass median aerodynamic diameter (MMAD) and the geometric standard deviation (GSD). The MMAD can be found by finding the 50^{th} percentile diameter for the fitted line of the log-probability plots, also known as a Probit Plot (Ramachandran, 2005).

Aim 2 of this research study looked to assess the differences in VOC total terpene mass concentrations across the four task zones. Similar to Aim 1, descriptive statistics of terpene mass concentrations were calculated, and plotted visually as a boxplot. The Mann-Whitney U Test was used to examine inter-task zone variation of mean terpene mass concentrations of each of the task zones compared to the office referent area. As a secondary analysis, descriptive statistics of the continuous VOC PID sensor data were calculated.

Aim 3 of the study compared total PMC to total terpene mass concentrations of each task zone via the Spearman rank-order correlation. The Spearman Rank-Order Correlation is a nonparametric (distribution agnostic) test that measures the strength and direction of association between two ranked variables. It does not make any assumptions about the distribution or frequency of the variables (Hauke & Kossowski, 2011). The outcome of the statistical test gives a result of correlation coefficient rho (ρ) and the

corresponding p-value. For this aim, a Spearman correlation was conducted for each individual task zone (trim, pre-roll, grow and office) to assess the association between PMC and VOC total terpene mass concentration.

Results

Aim 1

Descriptive Statistics

The purpose of Part A of this aim was to quantify and compare particle number concentrations (PNC) and particle mass concentrations (PMC) across each of the four individual task zones in the indoor cannabis production facility. Summary statistics for PNC, PMC and Ultrafine PNC can be found in Table 1 and histograms showing results of a lognormality assessment can be found in Appendix II.

Overall, it was observed that the greatest mean PNC levels were measured in the trim task zone, followed by the pre-roll, grow and office task zones. The mean particle number concentrations were 4.4×10^6 (IQR = $3.3 \times 10^6 – 4.8 \times 10^6$), 4.3×10^6 (IQR = $3.4 \times 10^6 – 5.5 \times 10^6$), 1.4×10^6 (IQR = $2.3 \times 10^5 – 2.4 \times 10^6$) and 2.7×10^6 (IQR = $2.3 \times 10^5 – 3.7 \times 10^6$) count/$m^3$ for the trim, pre-roll, grow and office task zones respectively. The boxplots in Figure 3 demonstrate the within- and between-task zone variability in PNC concentrations. Additionally, descriptive statistics were computed for Ultrafine PNCs across task zones as a secondary analysis to Aim 1. Ultrafine PNCs statistics were based on small sizes (2-3 sampling days) and are summarized in Table 1 below and plotted as a boxplot found in Appendix III, Table III-1. Ultrafine PNCs were highest in the trim area, followed by pre-roll > office > grow area. PMCs were highest in the trim task area (59 μg/m^3), followed by the pre-roll task area (50 μg/m^3), the grow task area (43 μg/m^3), and finally the lowest mean PMC exposures were detected in the referent office task area (19 μg/m^3) (Table 1). Within- and between-task zone variability in PMC exposures is plotted in Figure 4.

We observed a great amount of variability within the grow task area for PNC and PMC exposures over the 8 total sampling days, with an interquartile range of 2.3×10^5 - 2.4×10^6 particles/m^3 and 0.5 – 35 μg/m^3. During work shift observational periods for each sampling day, it was evident that the worker tasks in the grow area involved the greatest variety of work. Sampling days with higher exposures to PNC and PMC corresponded with days that involved a large amount of plant manipulation and/or plant harvesting. An example of a time series plot that illustrates the high variation in PNC exposures during the work day in which harvesting was occurring in the grow task area is illustrated in Figure 5. In contrast, on days where lower levels of PNC and PMC were detected, workers in the grow rooms were completing minimal trimming and watering of the plants. An example plot of low variation in PNC exposures during this type of work day is found in Figure 6. Additional details regarding observation of worker tasks during sampling days can be found in Appendix V.

Table 1. Summary Statistics for Particle Number Concentration, Particle Mass Concentration and Ultrafine Particle Count Concentration.

Location	n	Mean	Median	St Dev	IQR
Particle Number Concentration (count/m^3)					
Trim	8	4.4×10^6	3.9×10^6	1.9×10^6	3.3×10^6 – 4.8×10^6
Pre-Roll	8	4.3×10^6	4.2×10^6	1.4×10^6	3.4×10^6 – 5.5×10^6
Grow	8	1.4×10^6	1.1×10^6	1.4×10^6	2.3×10^5 – 2.4×10^6
Office	8	2.7×10^6	2.2×10^6	1.4×10^6	1.8×10^6 – 3.7×10^6
Particle Mass Concentration (μg/m^3)					
Trim	8	59.2	50.2	25.4	43.5 – 78.2
Pre-Roll	8	49.8	46.1	20.8	32.8 – 59.0
Grow	8	43.4	46.1	78.8	0.5 – 35.4
Office	8	18.5	16.7	6.3	13.8 – 21.1
Ultrafine Particle Count Concentration (count/m^3)					
Trim	3	1.6×10^{10}	1.6×10^{10}	1.1×10^9	1.5×10^9 – 1.6×10^{10}
Pre-Roll	3	1.0×10^{10}	1.1×10^{10}	5.1×10^9	7.9×10^9 – 1.3×10^{10}
Grow	3	3.7×10^9	2.6×10^9	3.4×10^9	1.8×10^9 – 5.0×10^9
Office	2	1.0×10^{10}	1.0×10^{10}	2.0×10^9	9.4×10^9 – 1.6×10^{10}

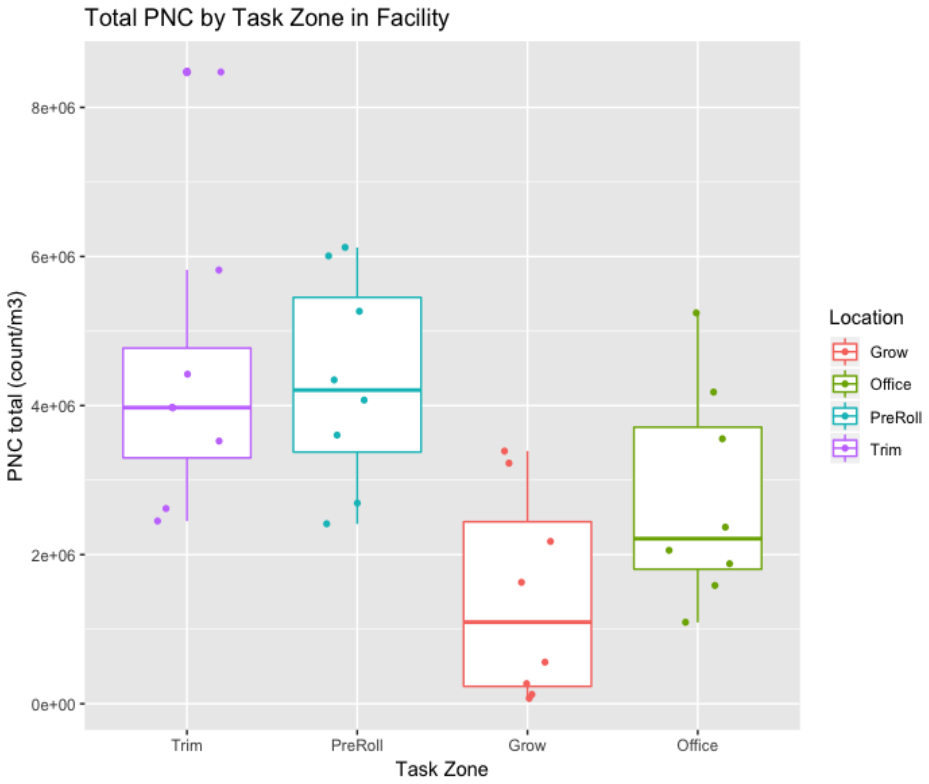

Figure 3. Boxplot of mean particle number concentrations (PNC) of the aggregate daily data for each sampling day across the four task zones.

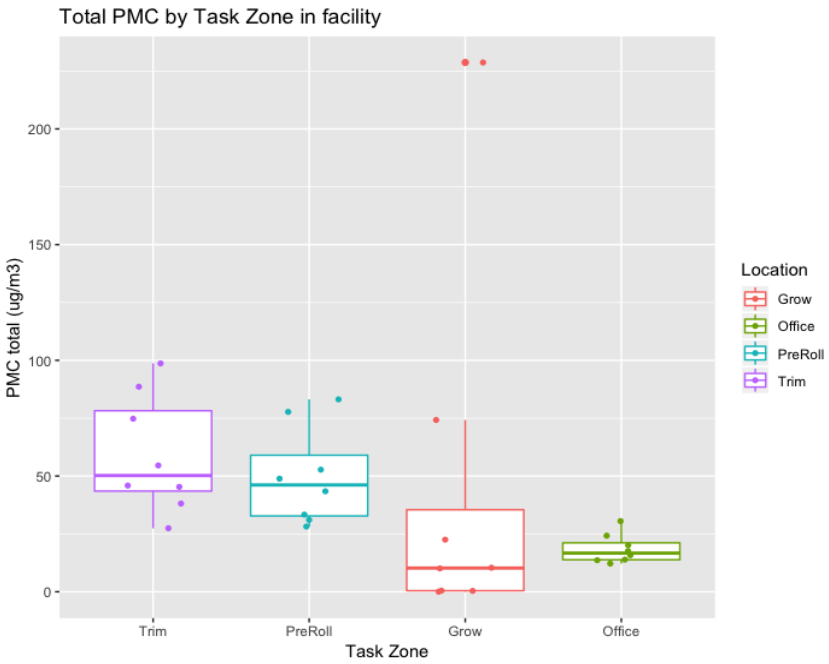

Figure 4. Boxplot of mean particle mass concentrations (PMC) of the aggregate daily data for each sampling day across the four task zones.

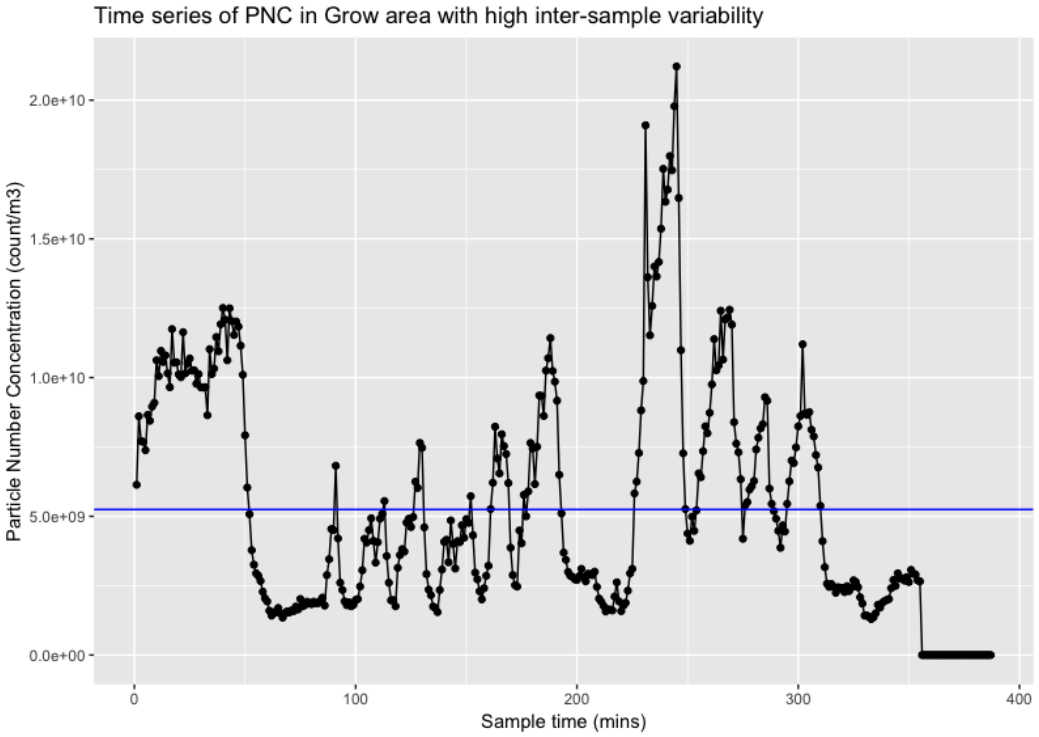

Figure 5. Time series scatterplot of high variation in PNC values in the grow task area during a single day of sampling (mean PNC value indicated by the blue horizontal line) (Dylos DC1100 Pro)

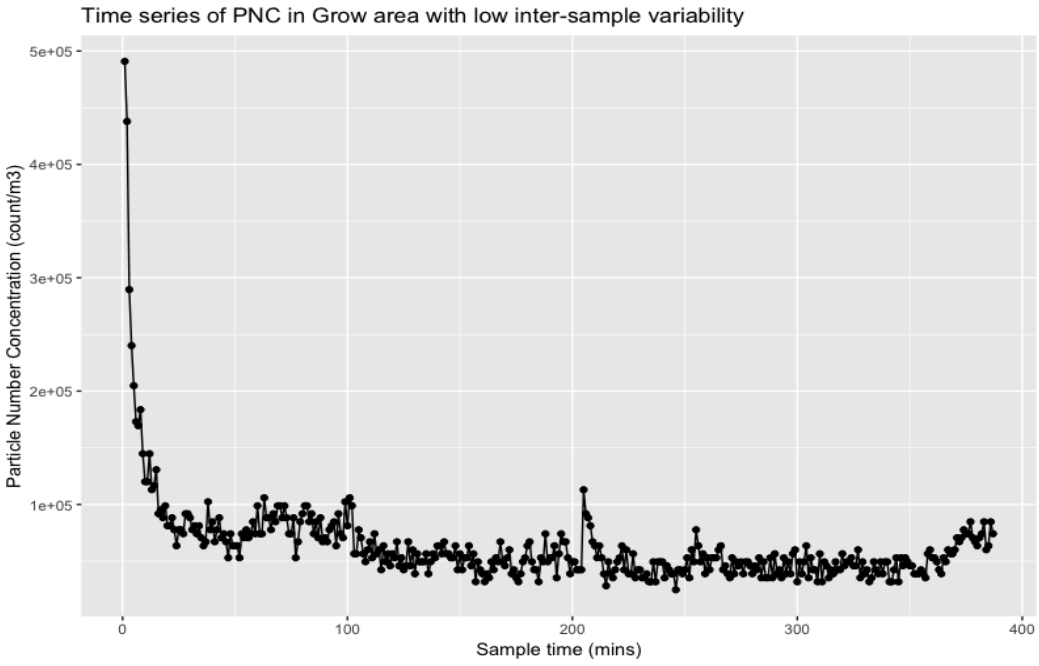

Figure 6. Time series scatterplot of low variation in PNC values in the grow task area during a single day of sampling (Dylos DC1100 Pro)

Part B of Aim 1 sought to address differences among particle size distributions (PSDs) across task zones within the facility. Following sample collection and analysis, particle size data was represented using a cumulative probability distribution, defined as the fraction of all particles with a diameter less than the cut point of interest as determined by the sampling equipment specifications (Ramachandran, 2005). Figure 7 below illustrates the particle size distributions based on the four size bins of the Dylos DC1100 Pro monitors. The mass median aerodynamic equivalent diameter (MMAD) and the geometric standard deviation (GSD) are given in Table 2. The task area with the greatest MMAD was the trim area with a value of 3.76 μm. The pre-roll and the office task areas had similar MMAD at 3.55 μm, while the grow rooms had the smallest MMAD value of 3.16 μm. The plots used for calculating the MMAD and GSD values can be found in Appendix III. Additionally, Probit plots of each task zone (Appendix III) and indicated that the cumulative mass fraction distributions do a good job at fitting the assumption of log-normality based on the shape and similarity to a straight, diagonal line.

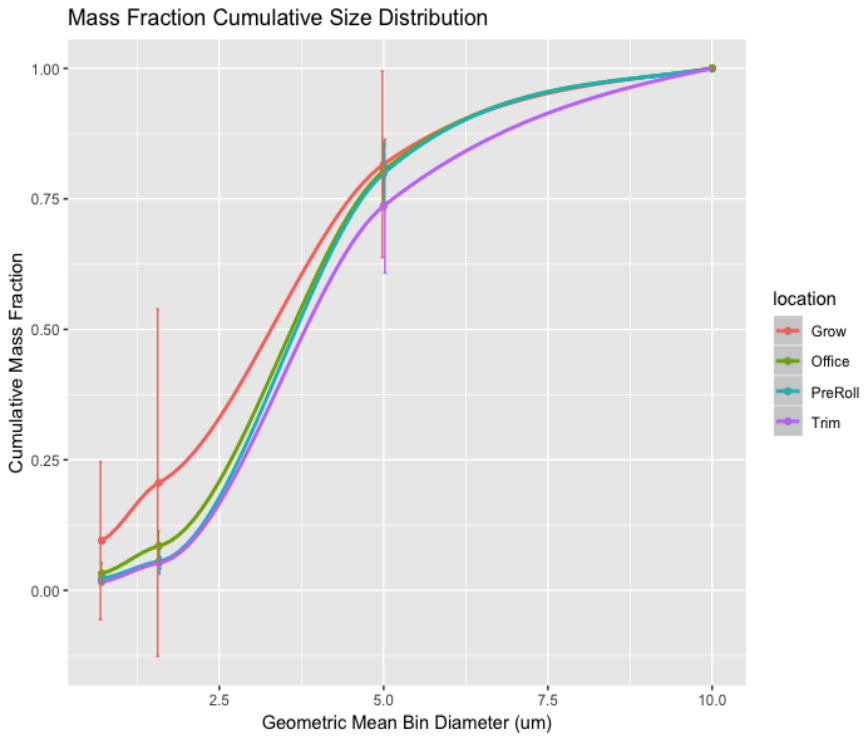

Figure 7. Cumulative distribution of particle mass fraction data based on bin diameter cut points. Data from each individual sampling day was aggregated to get a mean PNC value for each size bin, bin averages were then converted to PMC, and finally the PMC values for each bin for each sampling day were averaged across days within location, and those averages plotted to create the distribution lines. The vertical lines represent standard error from the task area samples (n=8 per task area).

Table 2. Summary Statistics for MMAD and GSD among task zones in μm

Location	MMAD (μm)	GSD
Trim	3.76	1.64
Pre-Roll	3.55	1.62
Grow	3.16	1.77
Office	3.55	1.66

Inferential Statistics

The Mann-Whitney U statistic tests the null hypotheses of specific aim 1a that there is no difference between PNC and PMC concentrations for a specific task area (trim, pre-roll, or grow) compared to the referent group (office). The null hypothesis is rejected if the p-value for the test is less than 0.05. In terms of PNC concentration, the Mann-Whitney test demonstrated that there is a significant difference in PNC concentrations in the pre-roll task area compared to the office reference group (p-value = 0.028). In contrast, PNC concentrations in the trim task area (p-value = 0.065) and the grow area (p-value = 0.10) were not significantly different compared to the office task area.

Results of the Mann-Whitney test showed that there was a significant difference in PMC concentrations between the trim task area (p-value = 0.00031) compared to the office referent group and for the pre-roll task area (p-value = 0.0003) versus the office referent area. However, the difference in PMC concentrations between the grow task area and the office area were not significantly different (p-value = 0.33).

Aim 2

Descriptive Statistics

The primary variables of interest for this specific aim are total terpene mass concentrations (mg/m^3) and VOC concentrations (mg/m^3) among the four unique task zones of interest. Data from the full-shift sorbent tube samples were used to calculate summary statistics (Table 3) and to plot inter- and intra-location variability (Figure 8). It is evident from this boxplot that the trim task area has the greatest amount of intra-location variability among samples. Sample sizes for the sorbent tube data ranged from 7 to 8 samples per task zone. The greatest value for mean total terpene mass concentration was detected in the trim task area at 34 mg/m^3. The other task zones resulted in average terpene concentrations of 11 mg/m^3 in the pre-roll area, 16 mg/m^3 in the grow area and finally 1.5 mg/m^3 in the referent office area. An

example plot showing concentrations of each of the twenty-one individual terpenes in the during a single sampling day in the trim task zone can be found in Appendix III (Figure III-4).

A secondary analysis of VOC concentration levels among task zones within the facility was conducted using the VOC PID sensor. Summary statistics are based on small sample sizes (2 to 4 samples per location) and can be found in Table 4. Average concentration levels in parts per million for VOCs were greatest in the trim task area task areas. In addition to sampling in each of the usual task areas, a single day of data was collected using the VOC PID sensor in the dry room during a plant harvest. The dry room task area reached the saturation point on the PID sensor of 53 mg/m^3 isobutylene equivalents within the first hour of sampling and remained at that concentration for the remainder of the sampling period.

Table 3. Overall VOC total terpene mass concentration by task area from sorbent tube sampling (mg/m^3)

Location	**n**	**Mean**	**Median**	**St Dev**	**IQR**
VOC Total Terpene Mass Concentration (mg/m^3)					
Trim	7	34	16	44	9.4 – 36
Pre-Roll	7	11	5.6	11	4.0 – 13
Grow	8	16	6.9	20	1.8 – 20
Office	7	1.5	1.5	0.85	1.1 – 2.2

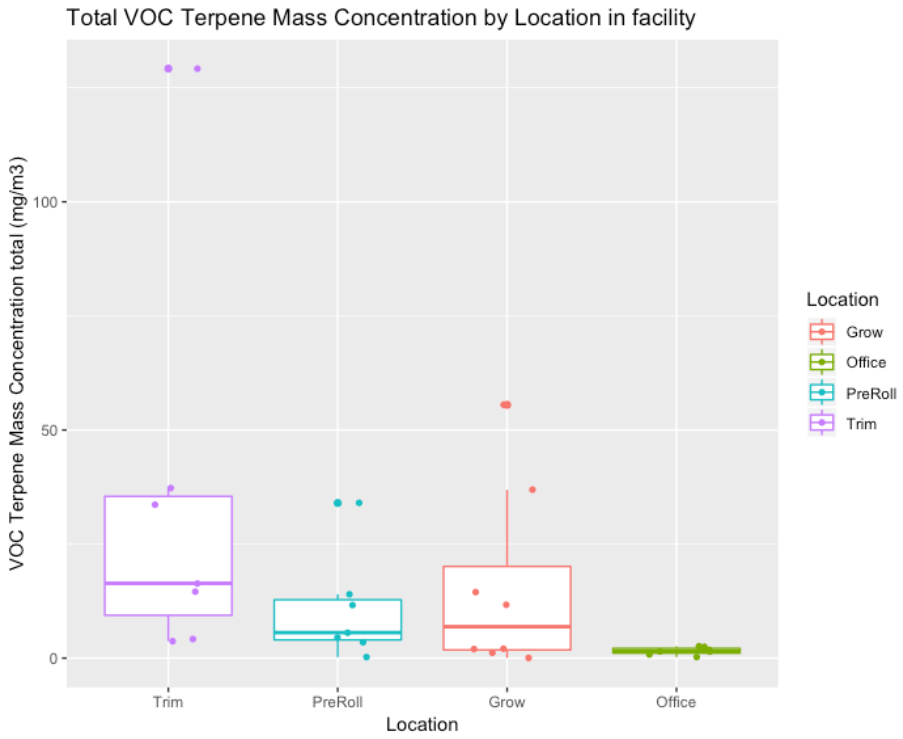

Figure 8. Boxplot of VOC total terpene mass concentration by task area (mg/m^3)

Table 4. VOC concentration by task area from PID Sensor sampling (mg/m^3-isobutylene equivalents)

Location	n	Mean	Median	St Dev	IQR
Trim	4	9.8	8.5	5.7	6.4 – 12
Pre-Roll	2	6.9	6.9	1.93	6.2 – 7.6
Grow	3	2.1	1.8	0.83	1.6 – 2.5
Office	2	1.7	1.7	0.48	1.6 – 1.9

Inferential Statistics

Similar to Aim 1, the Mann-Whitney test was used to test the null hypothesis of Specific Aim 2 that there is no statistical difference in total terpene mass concentrations in the trim, pre-roll or grow task areas when compared to the referent office space task area. Results of the statistical test indicate that total terpene concentrations in the trim area are significantly higher compared to the referent office concentrations (p-value = 0.0022). There was no statistically significant difference between pre-roll task area total terpene concentrations when compared to the referent group (p-value = 0.065) or between grow task area total terpene concentrations when compared to the office referent group (p-value = 0.48).

Aim 3

The purpose of the final specific aim is to determine if a correlation exists between total PMC and total terpene mass concentrations among the four specific task zones. The Spearman rank correlation test was used to estimate a rank-based measure of association between PMC and total terpene mass concentration. This test is typically used if the data do not come from a normal distribution. The outcome of the Spearman Rank Correlation test is a coefficient (rho) that is valued between -1 and 1. A correlation value of -1 indicates a strong negative correlation, a value of 1 indicates a strong positive correlation and a value of 0 demonstrates that there is no association between the two variables of interest.

A visual inspection of the data was conducted to determine if the relationship between PMC and total terpene mass concentration is linear. Plots of the relationships for each individual task zone and all the data combined are shown in Figures 9 through 13 below. Overall, the pre-roll task zone had the highest correlation coefficient (rho = 0.32, p-value = 0.50) of the four task areas, although it is clear by the magnitude of this coefficient and p-value that the relationship between PMC and total terpene mass concentration is not very strong. The trim task area resulted in a weak positive correlation between PMC and total terpene mass concentration (rho = 0.28, p-value = 0.56). In contrast, both the grow task area and the referent office task area resulted in correlation coefficients that indicated a weak, negative association between particulate mass concentration and total terpene mass concentration. The corresponding correlation coefficients are rho = -0.17 (p-value = 0.70) and rho = -0.14 (p-value = 0.78) for the grow and office task areas, respectively. Finally, when comparing PMC to total terpene mass concentration for all the data combined across the four task zones, the correlation coefficient indicated a statistically significant, positive relationship between the two variables (rho = 0.41, p-value = 0.03).

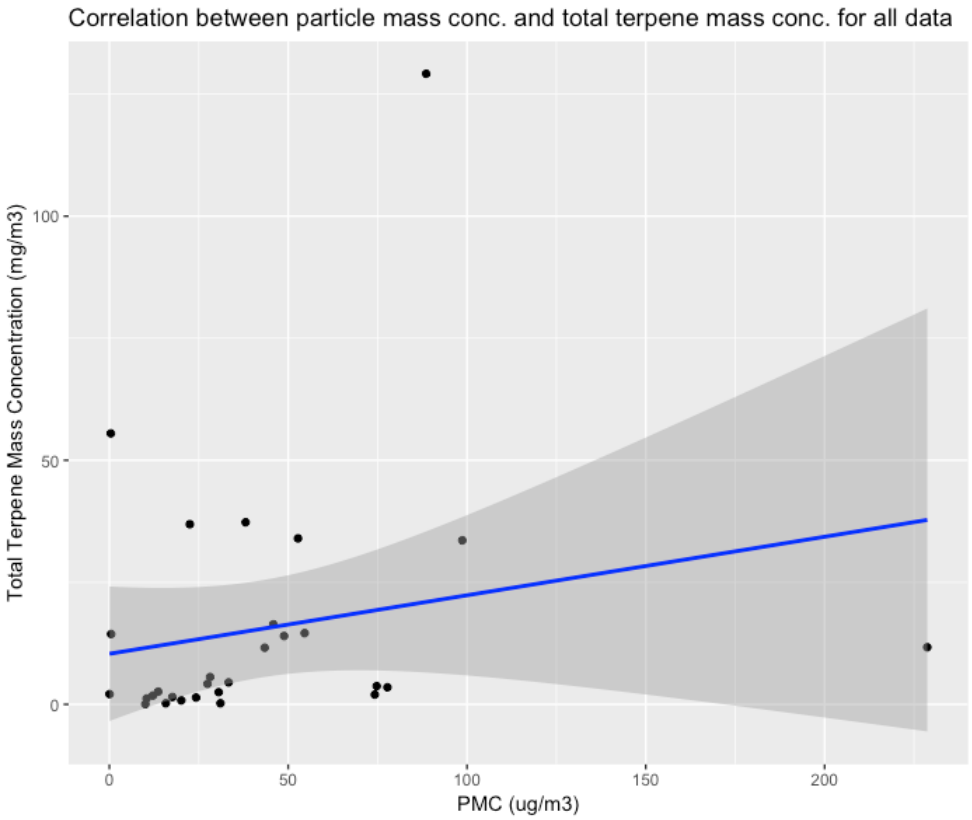

Figure 9. Scatterplot of PMC versus VOC total terpene mass concentration across all task areas

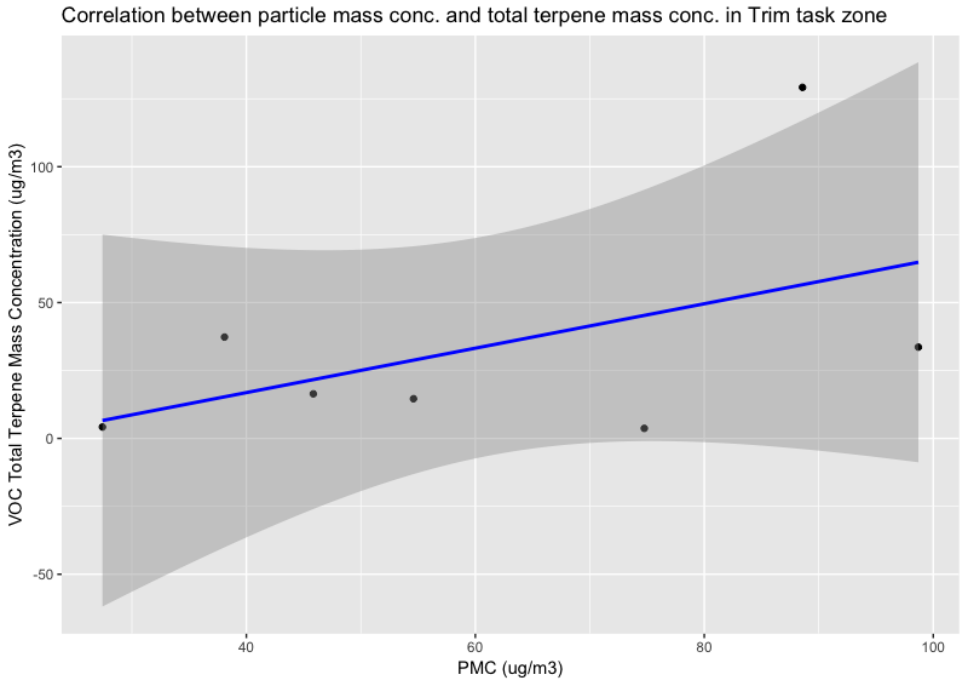

Figure 10. Scatterplot of PMC versus VOC total terpene mass concentration in trim task area

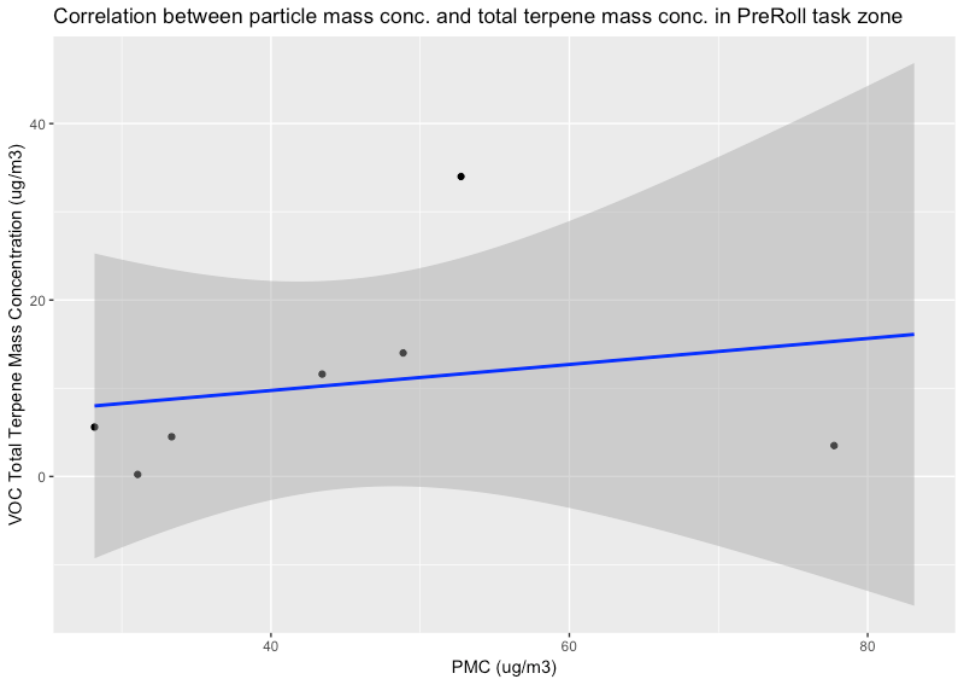

Figure 11. Scatterplot of PMC versus VOC total terpene mass concentration in pre-roll task area

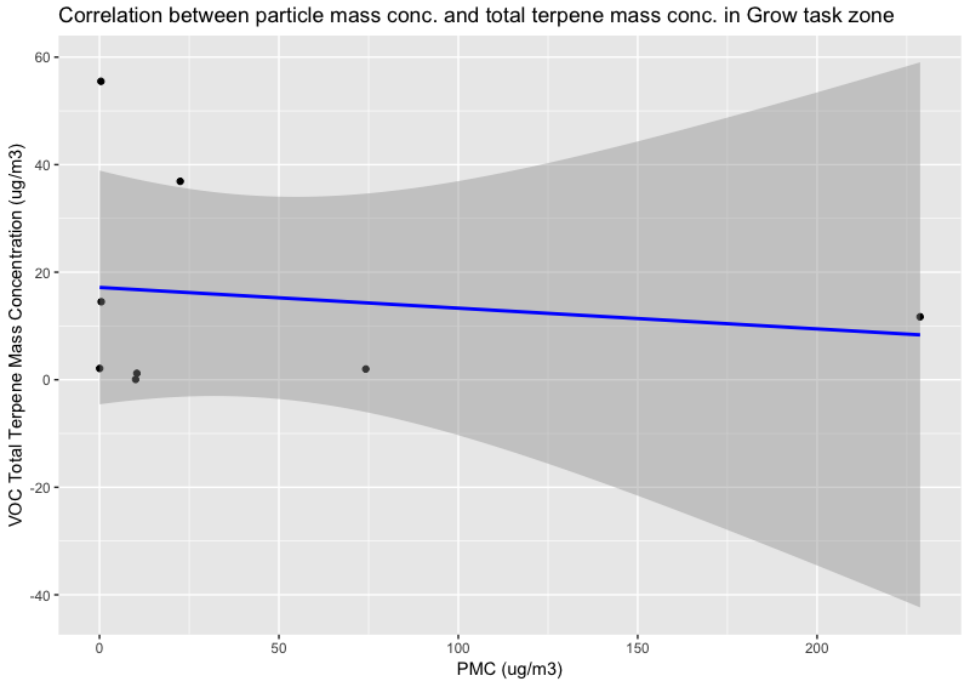

Figure 12. Scatterplot of PMC versus VOC total terpene mass concentration in grow task area

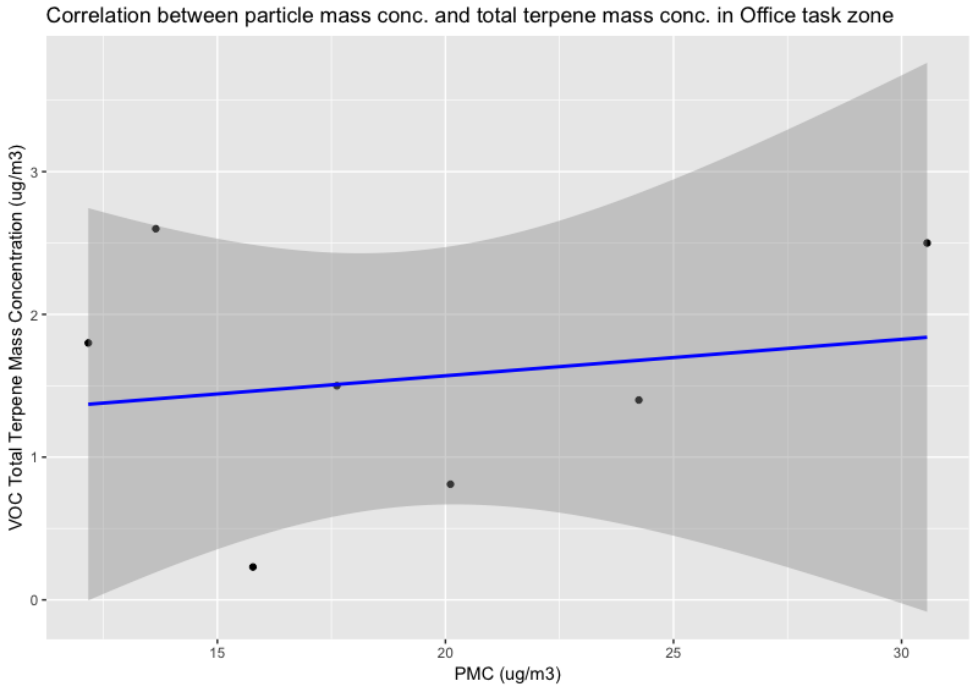

Figure 13. Scatterplot of PMC versus VOC total terpene mass concentration in office task area

Additionally, an evaluation of the correlation between the outcomes of the two VOC/terpene sampling devices was conducted. Figure 14 below demonstrates a visual inspection of the data via a scatterplot. It was found that the two VOC/terpene sampling devices are positively associated with a correlation coefficient of 0.53. However, this correlation value was not statistically significant (p-value = 0.12).

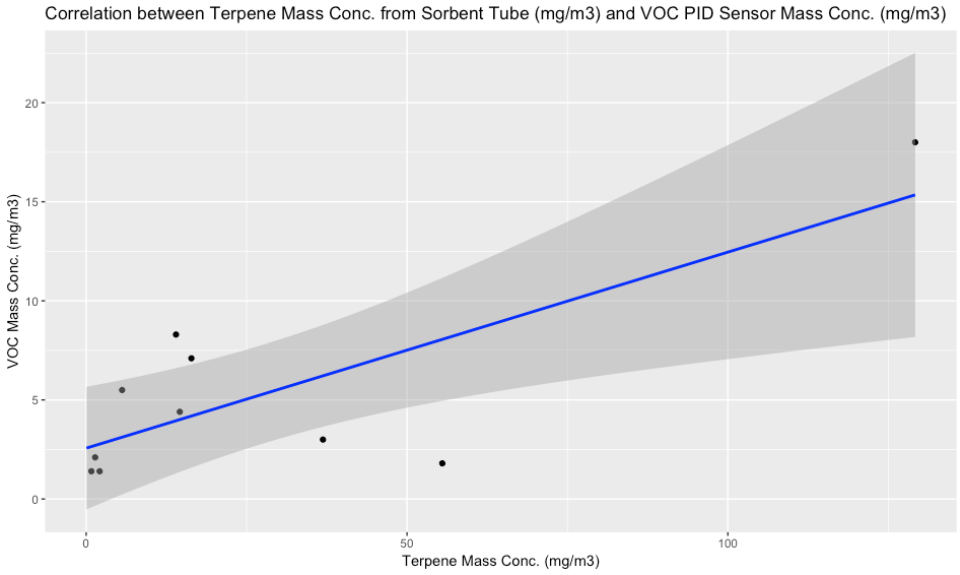

Figure 14. Scatterplot of total terpene mass concentrations from sorbent tube sampling (mg/m^3) versus VOC mass concentration from PID sensor sampling (mg/m^3)

Discussion

Findings from Aim 1

As hypothesized, particle number concentrations were greatest in task areas where constant manipulation and handling of the cannabis plants and plant materials occurred. The two task areas where particle number concentrations were greatest were the trim task area and the pre-roll task area. Area measurements from the sampling campaigns resulted in aggregated mean PNC values of 4.4×10^6 and 4.3×10^6 count/m^3 for the trim and pre-roll task areas, respectively. The high concentration of particle counts in the trim task zone is likely a result of the mechanical grinding of the cannabis flower into coarse powder, hand screening through size selective filters to separate small stems and seeds, or the mechanized filling of joint cones via the "knock-box" device. These tasks occurred periodically throughout the entirety of the full-shift sampling period and produced a noticeable level of organic dust. It was noted that during daily observations of worker activities in these task zones that several of the workbench spaces had visible accumulation of organic plant material (Appendix IV). In task areas where worker activities that involved manipulating the cannabis plants and materials were more intermittent, such as the grow task zone, the PNC exposure values were much lower. The mean particle number concentration over the 8 sampling days in the grow task zone was 1.4×10^6 count/m^3, with a range of $2.3 \times 10^5 – 2.4 \times 10^6$ count/m^3. Although workers in the office task area, which served as the referent group in this study, seldom handled unpackaged cannabis plant material, the mean PNC concentration was greater than that of the grow task area at 2.7×10^6 count/m^3. The PNC levels in the office area may be a result of the physical location of the production facility, as it is surrounded by various industrial facilities, a major interstate system, and a highly trafficked bridge connecting to the western part of the city. Other potential particle sources in the office area that were not present in the other areas of the facility include an office printer/copier, resuspended dust from carpeted floor and couch, and (compared to the grow area) greater foot traffic. In comparison, typical ambient PNC levels in an industrial area near Birmingham, England ranged from 1.0×10^4 to 6.0×10^7 particles/m^3 when sampling for particulate matter in the size ranges of 0.5 μm to 10.0 μm (Taiwo et al., 2014). In addition, typical PNC measurements in a grain handling and harvesting facility ranged from 1.2×10^6 to 5.8×10^7 particles/m^3 when sampling for PNC in the size ranges of 0.7 μm to 10.0 μm (Cho et al., 2010). When comparing the aggregate mean PNC values from each task zone to the referent office task zone, it was found that only the pre-roll task zone had a statistically significant difference in the mean PNC value compared to the office referent task zone (p-value = 0.028).

Overall, aggregate mean PMC concentrations from the sampling campaigns ranged from 59 $\mu g/m^3$ in the trim task area, 50 $\mu g/m^3$ in the pre-roll task area, 43 $\mu g/m^3$ in the grow task area and 19 $\mu g/m^3$ in the referent office area. Comparison of PMC averages in each task zone to the PMC average of the office referent task zone demonstrated that average PMC levels in both the trim and pre-roll task zones were significantly higher than the office (p-values = 0.0003 for both comparisons). As with the PNC comparisons, average PMC levels were not significantly different among the grow and office task areas. Few studies in the literature have reported measures of personal exposures to organic dusts from cannabis or hemp processing activities. Particle mass concentration levels for 8-hour full shift sampling found among the task zones in which this research study occurred were below those reported in research studies by Fishwick et al, Zuskin et al. and Couch et al. Fishwick et al. found that when sampling in the inhalable fraction for workers processing hemp, personal organic dust exposures ranged from 10.4 – 79.8 mg/m^3, however the length of sampling was not recorded and the study did not note whether or not the personal samples were task- or location-specific measurements (Fishwick, Allan, Wright, Barber, & Curran, 2001). Zuskin et al. reported high personal exposure levels during production activities when sampling for an eight-hour work shift in the respirable range (1.3 – 38.4 mg/m^3) in a hemp production facility (Zuskin, Kancelijak, Pokrajac, Schachter, & Witek, 1990). Again, this study did not address whether personal respirable PM samples on workers were from generalized work activities, or if they occurred during a single task or in a single location within the facility. Couch et al. reported worker area sampling results that ranged from 0.01 to 20.5 mg/m^3 during a typical 45-minute grinding operation at a cannabis production facility (Couch, et al., 2018).

None of the samples collected in this study resulted in a PMC value that was greater than the US OSHA 8-hour Time-Weighted Average (TWA) Permissible Exposure Limit (PEL) for Particulates Not Otherwise Regulated (Total) of 15 mg/m^3 or the ACGIH TWA Threshold Limit Value of 10 mg/m^3. Based on this standard, the facility in which this study took place is compliant with occupational regulations pertaining to exposures to particulate matter. However, due to the fact that workers in the facility have reported experiencing health effects at the lower PMC levels that were sampled during this research study (Ghodsian, N., M.S. Thesis, 2019), it indicates that exposure to particles at levels below the OSHA PEL may have the ability to cause irritation or other serious health effects. Bouhuys et al. and Zuskin et al. reported a high prevalence of byssinosis (77% and a range of 47-67%, respectively) and acute respiratory symptoms such as decreased FEV_1, chest tightness, cough and dyspnea in healthy adults after just an hour of dust exposure (Bouhuys et al., 1967; Zuskin et al., 1990). Currently, there is no standard in place that regulates occupational exposure specifically to organic dusts from cannabis plants and related materials. Based on the evidence reported from this study and from the few studies published

in literature regarding occupational exposures to cannabis, we recommend that Washington State consider developing an exposure standard specifically for cannabis dusts that is based on health evidence. In the interim, The ACGIH TLV standard for cotton dust could be implemented as an interim occupational exposure standard for these facilities until a cannabis standard is developed and adopted. The ACGIH TLV for cotton dust is 0.1 mg/m^3 TWA_{8hour}. However, a cannabis-specific standard may need to be even lower since it has been suggested that components of cannabis may have an even greater pro-inflammatory potential as compared to cotton dust (Davidson, et al., 2018).

Results from the particle size distribution analysis of Aim 1b were consistent with aerosol distributions of typical occupational settings. Ramachandran et al. describes occupational aerosols to be lognormal distributed with GSDs ranging from 1.5 to 3.5 (Ramachandran, 2005). Examples of MMADs in agricultural workplace settings include air samples collected from inside dairy barns with MMAD (GSD) of 13.5 μm (2.1), and samples collected from a grain facility with MMADs (GSDs) for corn grain dust of 13.2 μm (1.8) and wheat dust of 13.4 μm (2.1) (Kullman et al., 1998; Boac, 2009). In the case of this research study, MMADs ranged from 3.16 to 3.76 μm and GSDs ranged from 1.62 to 1.77, which indicates that particles in the cannabis facility were on average smaller than those observed in the agricultural workplaces cited above.

Findings from Aim 2

Results of VOC total terpene mass concentrations aggregated averages across task zones differed from PNC and PMC values. Overall, aggregate mean total terpene mass concentration exposures from the sampling campaigns ranged from 34 mg/m^3 in the trim task area, 11 mg/m^3 in the pre-roll task area, 16 mg/m^3 in the grow task area and 1.5 mg/m^3 in the referent office area. Since it is the terpene compounds that are responsible for the unique scent of the cannabis plant it was hypothesized that task zones that required a great deal of plant manipulation and thus a release of the aroma, such as grinding or trimming, would result in the highest levels of total terpene exposures. This was found to be true in the case of the trim task area, but the grow task area resulted in the second highest value of aggregate mean total terpene mass concentration. Comparison of total terpene mass concentration averages in each task zone to the average of the office referent task zone resulted in only the Trim task zones having statistically significant differences in average total terpene mass concentration levels compared to the office (p-value = 0.002).

Eriksson et al. described occupational illness in sawmill workers that was related to terpene exposures (Eriksson, et al., 1997). Additionally, terpenes present unique physio-chemical properties that allow them to be readily absorbed through the skin and gastrointestinal tract (Davidson, et al., 2018). This indicates a

potential for health concerns associated with occupational exposure to terpenes. Currently, the only occupational standards regarding terpene exposures have been established in countries in the European Union (EU). These eight-hour time weighted average (TWA) exposure standards for terpenes range from 20 to 100 ppm (which corresponds to 46 to 229 mg/m^3 isobutylene equivalents) (Davidson, et al., 2018). Our measurements were typically below 50 mg/m^3, however there were four samples greater than 50 mg/m^3, and two samples greater than 100 mg/m^3. Although this research study does not differentiate whether adverse health effects are a result from exposure to particulates or terpenes, since the U.S. lacks a standard at the state or federal level for exposure to terpenes in occupational settings, an EU standard might be considered for adoption.

Findings from Aim 3

Out of all of the correlation tests that were conducted to examine the relationship between particle mass concentrations and total terpene mass concentrations for each of the individual task zones, the highest was produced by the pre-roll task zone (rho = 0.32). This indicates that when comparing PMC to total terpene mass concentration among different task zones within a cannabis production facility, the relationship between the two measurements is weak. In this study, the trim and pre-roll task zones had weak positive correlation coefficients (rho = 0.28 and 0.32, respectively; neither of which were statistically significant). This suggests that as PMC concentrations increase, the total terpene mass concentration also increases; however, the relationship between the two variables is not very strong. In contrast, the grow and office task zones had weak negative correlation coefficients (rho = -0.17 and -0.14, respectively). The current data set is limited by small sample size - we only had eight pairs of VOC and PMC measurements per location. It is possible that with a larger data set statistically significant associations between VOCs and PMCs would emerge. Future areas of research may involve creating a predictive model that includes variables that account for temperature, humidity, ventilation/air exchange rates which would further explore how these two variables (PMCs and VOCs) may be related in this occupational setting, if at all.

Limitations

There are several limitations in this study that are notable and could have been addressed with more time and resources. The most significant limitation of this study is the reliance on area concentration measurements, rather than personal exposure measurements, to characterize and quantify PNC, PMC and VOC total terpene mass concentration levels across task zones within the facility. The area samples may not be representative of breathing zone exposures of workers that may have been moving between different microenvironments during a typical work day. Due to the lack of previous literature that

addressed particulate matter and terpene exposures in the cannabis production industry, it was necessary to first understand what levels of these contaminants existed in this type of facility and if exposure levels differed among different worker tasks. Ideally, measurements of airborne contaminants would have been done at the individual level rather than the task level. This would mean that in a perfect sampling scenario each employee at the site would wear personal monitoring devices for the entirety of their work shifts, over multiple sampling days. Having a more extensive set of air samples would have made the data set more robust.

Secondly, time and budget constraints made it only possible to conduct two full sampling campaigns at a single facility. This meant that for the sampling equipment in which multiple devices were not available to collect data in all of the task areas on a single sampling day, the device only collected data in one area for the work and then was rotated to another area on the subsequent sampling day. The result of this constraint was very small sample sizes in task areas for the P-trak ultrafine particle counter and the VOC PID sensor (sample sizes ranged from 2 to 4 sampling days). Although the Dylos devices and the sorbent tubes were able to be deployed in each task area simultaneously during a sampling day, time constraints made it so that most of the task areas ended with seven or eight full-shift days of sampling data. Again, if more devices and days of sampling were achieved, this would have improved the overall quality of the data that was collected at the facility. Additionally, air sampling only occurred at one specific cannabis production facility in Seattle, WA. Sampling at multiple cannabis producers and processors and at varying scales of production would have resulted in a more accurate representation of the varying occupational exposure levels that could occur when working with this type of plant product.

Finally, there was a significant limitation with the use of the Dylos DC1100 Pro sampling instruments as our primary measurement device for PNC and PMC. First, it was not possible to calibrate or zero the Dylos before each day of sampling because there were no such procedures to do so and the devices came pre-calibrated by the manufacturer. Additionally, due to the failure of the typical pump and filter sampling scheme and gravimetric analysis to quantify particle mass concentrations, the research relied on the conversion of the Dylos PNC values to PMC measurements. Several assumptions had to be made in order to utilize the equation to make this conversion. First, it was assumed that the aerosols that were being captured had a density of 1.5 g/cm^3. This was based on literature that reported organic dust average particle densities because there was no literature available regarding the particle density of cannabis plant material. We are unsure if this assumption was an under- or overestimate of the true particle density. Moreover, it was decided to use the geometric mean diameter of each of the Dylos bins, which is then cubed, to be included in the equation to convert PNC to PMC. The use of the mid-point of the bin, rather

than the lower or upper end points of the size bin could have significantly affected the resulting particle mass concentrations.

Future Areas of Study

Due to the fact that this was a pilot study, area measurements and small sample sizes were the core of the experimental approach behind this research. In future studies, aerosol measurement should be conducted at the individual level as personal samples, in the workers' breathing zone. A larger study should be conducted with multiple employees being sampled over repeated days to increase sample sizes. Several study sites should be identified across varying levels of production capabilities in order to get a better understanding of exposure variations between different size production and growing facilities. Incorporating these factors into a larger study would provide more robust information regarding occupational exposure to airborne contaminants in this field.

Another area of improvement to this study to be considered in the future would be to incorporate more sophisticated sampling equipment for particle measurements. While the Dylos DC1100 Pro devices are a reliable low-cost particle sensor, it only had four size bins for the separation of particles. A more advanced instrument, such as the TSI 3300 Optical Particle Sizer which has 16 programmable size bins, would better characterize particle size distributions and particle mass concentrations in each task zone. Finally, it would be ideal to refine sampling using the typical pump and filter set-up as to incorporate gravimetric analysis in order to estimate particle mass concentrations.

Conclusions

In the United States, the legalization of medical and recreational cannabis use and sales over the past few decades has led to the development of a unique and thriving industry in many states. As more states begin to enter into the recreational market in the upcoming years, it is projected that the number of full-time workers is expected to double (McVey et al., 2016). In this study, we quantified and compared particulate matter and volatile organic compounds exposure levels among cannabis workers in four different task zones by conducting area air sampling in an indoor production facility. This study aimed to reduce the current gap in occupational exposure knowledge in this industry by providing full-shift and task-specific PM and VOC measurements. Currently, there are few cannabis-specific research studies available in the literature and none that have addressed our research question of interest. Our results showed that the task areas that required constant cannabis plant handling and manipulation had greater levels of PNC, PMC, total terpene mass concentration and non-specific VOC mass concentrations. PMC and total terpene mass concentrations were significantly higher in the trim task area compared to the referent office task area. PNC and PMC were significantly higher in the pre-roll task area compared to the referent area. While the majority of our PMC and terpene mass concentration measurements were below applicable occupational exposure standards, a few did exceed or come close to exceeding those threshold values. When examining the correlations for each task zone between PMC and total terpene mass concentrations, we did not find any statistically significant task-specific correlation coefficients. However, when combining all the data together, we found a significant positive association between PMC and total terpene mass concentration. It is likely that the main limitation of our study – small sample size – contributed to the lack of task-specific correlations in our results.

Rarely are researchers able to be at the forefront of studying an emerging industry. Our results indicate the importance of continuing occupational exposure and health research among cannabis workers. Our study showed that there is a need to adopt relevant occupational exposure level standards until cannabis-specific standards are implemented, as some of our measurements exceeded or came close to exceeding other relevant agricultural organic dust and volatile organic compound occupational threshold values. Additionally, our results can serve as the baseline of airborne contaminant exposures in an indoor cannabis production facility and inform employers of the hazards that may be present in their workplace and the types of control measures that may need to be implemented.

This study only scratched the surface of characterizing the various airborne contaminants and what worker's exposures may be in this industry. There are many other important occupational components of

cannabis growing and production that should be considered in future areas of research. They include other biological hazards such as bacteria, fungi, viruses, and endotoxin, as well as physical and chemical hazards. While our study helped to quantify and characterize full-shift and task-specific PM and VOC hazards in this emerging industry, the health and safety of workers is a major public health concern, and needs to continually be addressed through ongoing research and policy implementation.

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Appendices

Appendix I. - Sampling Standard Operating Procedures (SOP)

Cannabis Respiratory Study: Indoor Air Contaminant Characterization
Brynne Silvey
Revised: April 5, 2019

Location

- Seattle, WA SODO neighborhood

Sampling Dates

- Preliminary indoor air measurements – October 9, 2018
- Full indoor air measurements – December 3 - 14, 2018 and January 14-25, 2019

Specific Aims

Aim 1. Determine the differences in PM mass concentrations and size distributions among four specific task zones within an indoor cannabis production facility

Aim 1a. Measure and compare PM mass concentrations (PMC) and particle number concentrations (PNC) associated with the four task zones: Trim, Pre-Roll, Grow and Office using a Dylos DC1100 real-time optical particle counter with 4 different size bins and the Ptrak Model 8525 Ultrafine Particle Counter.

Aim 1b. Quantify and compare the particle size distributions associated with the four specific task zones using mass fraction data from the Dylos DC1100 real-time optical particle counter with 4 different size bins.

Aim 2. Quantify and compare VOC total terpene mass concentrations, measured using sorbent tubes and GC/MS associated with four specific task zones (Trim, Pre-Roll, Grow and Office) within an indoor cannabis indoor production facility.

Aim 3. Compare total PMC to total terpene mass concentrations.

Study Design

- Area samples, collected in 4 specific work areas
- Repeat sampling (4-6 repeat samples) in the same work areas
- Specific work areas:
    - Front office (serves as the control location)
    - Grow room – growth phase
    - Trimming room
    - Production area – joint rolling

Sampling and Analysis

- Gravimetric, integrated PM
    - Pump & IOM cassette
    - PVC filter media
    - Wilcox Lab, Mettler Toledo Mass Balance
- Real time PM and particle size distribution
    - Anticipate mix of ultrafines (SVOC in grow rooms) and coarse material (plant fragments, mold spores)
        - P-trak Ultrafine Particle Counter
        - Dylos Air Quality Monitor

- Integrated VOCs (terpenes): sorbent tubes with GC/MS analysis
- Continuous Real-Time VOCs: VOC PID Sensor with calibration curve from decay model

Table I-1. Example sampling timeline and corresponding equipment used and rotated throughout the various task zones for this research study

	Location & Equipment Needed			
Day	Trim	Grow	Pre-Roll	Office
Week 1 - Monday	Pump & filter Pump & sorbent tube Dylos Ptrak VOC PID Sensor	Pump & filter Pump & Sorbent tube Dylos	Pump & filter Pump & Sorbent tube Dylos	Pump & filter Pump & Sorbent tube Dylos
Week 1 - Friday	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos Ptrak VOC PID Sensor	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos
Week 2 - Monday	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos Ptrak VOC PID Sensor	Pump & filter Pump & sorbent tube Dylos
Week 2 - Friday	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos	Pump & filter Pump & sorbent tube Dylos Ptrak VOC PID Sensor

*Repeat schedule for additional sampling days

Equipment & Materials Checklist

- Pumps - regular flow @ 2 L/min (5)
- DryCal set for regular flow @ 2 L/min
- Low flow pumps set for low flow @ 200 mL/min (5)
- Low flow DryCal set for low flow @ 200 mL/min
- IOM Samplers (5), plus blank (1)
- PVC filters (5), plus blanks (1)
- Sorbent tubes for VOCs (4), plus blanks (1-2)
- Calibration Jug
- Dylos Air Quality Monitor DC1100 Pro, with chargers/power adapters (4)
- P-Trak Ultrafine particle counter Model 8525, with batteries and power adapter
- VOC PID Sensor
    - Battery pack
    - USB drive to transfer data to laptop
- Field Data Logs
    - Particulate filter, Dylos, and Ptrak sampling

    - VOC sorbent tube sampling and VOC PID Sensor
- Daily Task/Activity Observation forms
- Basket to hang Dylos in for the grow room (2)
- Floor Plan/Layout diagram of Solstice Facility
- Masking tape/labels
- Scissors
- Permanent markers
- Aluminum foil
- Nitrile gloves
- Ziplock™ bags for filters/media
- Power strip
- Box to transport equipment
- PC computer to complete a daily download of the real-time data (IH Teaching Lab)

Equipment Procedures

Preparation of pump and filters

Weighing the filters

- Take apart IOM sampler, wash with DI water and place on aluminum foil to dry
- Take Zefluor 25 mm filter out of equilibrium chamber with set of forceps
- Place filter inside 2-part filter holder of the IOM sampler
- Using forceps, pass the filter and holder through the electrostatic field
- Tare the scale
- Using forceps, place the filter on the scale and close the weighing chamber
- Wait for reading to steady and record the weight
- Repeat for 2 more measurements
- Take the filter + holder and assemble in full IOM sampler setup, cover with foil
- Place in equilibrium chamber until sampling, at least 2 days

Calibrating the pumps

- Take one of the prepared IOM samplers to use at the calibration sampler (label with MMDDYY_Cal)
- Connect the IOM sampler to the Calibration Jug tubing that allows the IOM sampler to hand inside the jug when closed, seal the calibration jug.
- Connect tubing to the pump and the DryCal
- Turn on pump, adjust the flow so that the reading on the pump is set to 2 lpm
- Set DryCal to continuous measurements, press enter to begin cycle
- Adjust the pump flow with the screwdriver until it reads Avg 2 lpm on the DryCal
    - Record the Avg to 2 decimal places on “pre-cal” on field notes
    - Record actual reading of flow on pump to verify in the field
- Disassemble and return IOM Cal sampler to foil and store in equilibrium chamber until sampling day
- Repeat calibration for verification in the field
- Post-Cal using the same DryCal & Calibration Jug setup in the field. Use the IOM sampler that was used for the full day sampling instead of the IOM Cal sampler
- Record post-cal value

Post-weighing filters

- Let IOM samplers equilibrate in chamber for at least 2 days.
- Repeat steps for disassembling the samplers and weighing as done in the pre-weigh steps

Dylos Air Quality Monitors DC 1100

- Clear the Dylos sampling history
    - with the “battery/charge” button flipped up, press the on/off button

    - press the “mode” button until the “clear history” comes up
    - press “select” to clear history
- Synchronize time on Dylos
- Fully charge all the Dylos
    - connect the Dylos to the AC adaptor, connect the AC adaptor to a wall outlet
    - flip the side switch up towards the “battery/charge” label
    - make sure the Dylos are off by pressing the on/off button
    - when the Dylos are fully charged, disconnect them from the AC adaptor and flip the side switch down “battery/charge” to ensure the sampler is fully off
- Turn the Dylos off and flip the side switch down
- When ready to start logging data, turn the Dylos on by flipping the “battery/charge” side switch up until the LCD display is on; take note of the start time
- Face the back of the Dylos (where the inlets and outlets are found) towards the production/grow area; ensure the inlets and outlets are not obstructed
- When sampling is complete, check that the Dylos is still running; record the end time

Downloading Data

- Obtain a PC computer
- Connect the Dylos to the PC using the USB-to-serial cord
    - check that it installs drives (should occur automatically)
- Find the COM port and record it
    - Open Device Manager on PC / Select Ports (COM & LPT) / “Prolific USB-to-Serial Port (COM____)”
- Use PuTTY to download all data (Dylos Manual)
    - Download PuTTY software (Putty.exe) online to a PC computer
    - Plug in Dylos and turn it on
    - Open and run PuTTY
    - On the left hand side on the Configuration screen select “Serial” and set the parameters: 9600 baud, 8 bits, no parity, 1 stop bit, no flow control)
    - Select “Session” on the left hand of the screen and then select “Serial” radio button
    - Select the “Logging” category on the left hand side, select “All session output” and “ALways append to the end of it” buttons
    - Click “browse” button, name your file and select its desired saved location
    - To save the setup settings, select the “session” category and enter the name of the session
    - Click “open” and the PuTTY terminal will open
    - In the PuTTY terminal, enter a capital “D” followed by “Enter” to download the internal memory (The D will not appear on the screen)
    - The data should output with the oldest samples shown first and the newest last. Output is in #/0.01 ft^3
    - save as .csv or .txt
    - Ensure all data is saved
    - Clear the history on the Dylos

P-Trak Ultrafine Particle Counter

- supply power with 6 individual AA batteries into the battery pack, or use the AC adaptor plugged into a wall outlet
- Ensure that the alcohol capsule is sufficiently filled and insert the cartridge into the appropriate cavity
- Attach the inlet screen (helps prevent large particles and fibers from entering instrument), insert until firmly snaps into place. Attach one end of sample tube to inlet screen, attach the other end of the sample tube to the telescoping probe
- Select proper mode of operation

    - "Data Log Mode" - record particle concentration readings over a period of time, sore those readings in memory to be downloaded later
- Press "on/off" switch (back of instrument) and hold for 2-3 seconds to turn on P-trak, instrument undergoes 60 second warm up countdown sequence
- Before sampling, conduct daily zero check
    - remove attached sample tube from inlet screen
    - attach supplied zero filter to inlet screen
    - leave the zero filter attached for 30 seconds, to make sure reading is stable
- P-trak will automatically go to survey mode and main menu will be displayed, change mode using the keypad.
    - Sample mode - used for capturing single data points
    - Setup mode - used for reviewing logged data, single data points, statistics.
    - Log mode - displays current log mode, used for changing mode and starting data logging
- P-trak counter displays the measured particle concentration in units of pt/cc
- log interval menu allows you to view the current logging interval during LOG MODE 1
    - default values for log intervals are set at 1 second, 1 min, 5 min, 15 min, 30 mins
- to begin a data logging session, select "LOG MODe and press "enter arrow", the p-trak will begin recording logged data into the instrument memory
    - note - logging interval must be adjusted from the Setup menu, before beginning the logging session

Downloading Data

- Install the TrakPro Software on a computer
- Locate an available RS-232 serial port on computer (COM1 or COM2), connect the RJ-45 connector to the P-trak Communications Port
- Turn on P-trak, start TrakPro software
    - Select "Instrument Setup, Communications" in TrakPro software
    - Select correct serial port, then select "test"
    - select "ok" to accept the setup

VOC PID Sensor

- Ensure that memory chip is placed face-down in slot on sensor
- Connect battery pack to power inlet on lower side of the sensor
- Turn on power on battery pack
- Ensure that red light indicating power is being supplied to the sensor is on, and ensure that blue light on PID sensor is illuminated
- Once power is supplied, the sensor will begin data logging
- Once sampling is completed, turn off battery pack and sensor will finish data logging.
- Remove memory chip and insert into USB drive
- Plug in USB drive into available computer
- Open file labeled "NO DATA" and save as an Excel

Table I-2. Example field data log

Pump ID	Sample ID	Initial Flow	Final Flow	Avg Flow (lpm)	Start Time	Stop Time	Run Time (Min	Total Volume (L)	Volume Conversion (L to m3)
IOM Samplers									
Trim	MMDDYY_Trim								
PreRoll	MMDDYY_PreRoll								
Grow	MMDDYY_Grow								
Office	MMDDYY_Office								
Filter/Sample ID	**Pre-weight 1**	**Pre-weight 2**	**Pre-Average**	**Post-Weight 1**	**Post-Weight**	**Post-Averag**	**Post-Pre (mg)**	**Mass Conversion (mg to**	**Mass Concentration (ug/m3)**
MMDDYY_Trim									
MMDDYY_PreRoll									
MMDDYY_Grow									
MMDDYY_Office									
MMDDYY_Blank									
Real-Time Monitors									
Monitor Type	**Location in Buildin**	**test number**	**start time**	**stop time**					
Ptrak	Grow								
PID	Office								
Dylos	Trim								
Dylos	PreRoll								
Dylos	Grow								
Dylos	Office								
Sorbent Tube VOC Samplers									
Pump ID	**Sample ID**	**Initial Flow**	**Final Flow**	**Avg Flow (mLpr**	**Start Time**	**Stop Time**	**Run Time (min**	**Total Volume (mL)**	
Trim	MMDDYY_Trim								
PreRoll	MMDDYY_PreRoll								
Grow	MMDDYY_Grow								
office	MMDDYY_Office								

Table I-3. Example daily worker task and activity observation log

Daily Task/Activity Observation Log		
Location	**Time Period during which task was performed**	**Task Description and Comments**
Trim	8:00 am - 10:00 am	
	10:15 am - 12:00 pm	
	12:30 pm - 2:00 pm	
	2:15 pm - 4:00 pm	
Pre-Roll	8:00 am - 10:00 am	
	10:15 am - 12:00 pm	
	12:30 pm - 2:00 pm	
	2:15 pm - 4:00 pm	
Grow	8:00 am - 10:00 am	
	10:15 am - 12:00 pm	
	12:30 pm - 2:00 pm	
	2:15 pm - 4:00 pm	

Appendix II. – Methods: Supplementary Tables and Figures

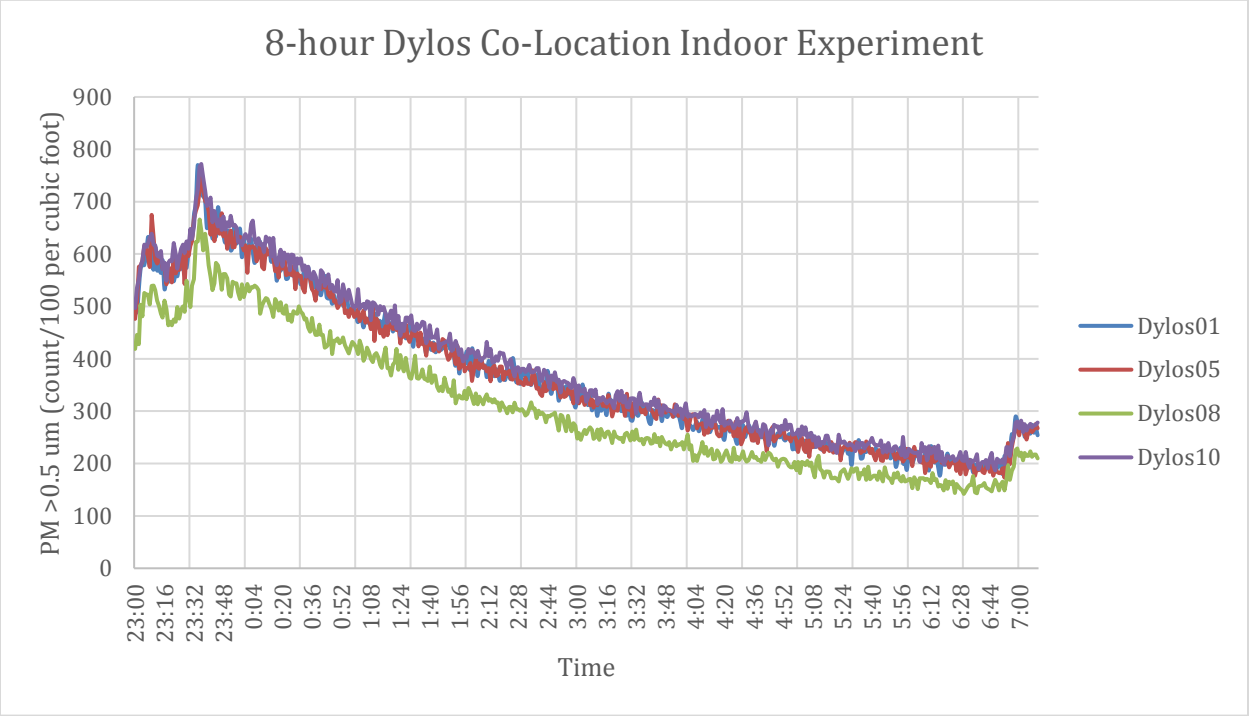

Figure II-1. Indoor 8-hour co-location experiment of the four Dylos monitors that were used in the sampling campaigns in the indoor cannabis production facility

Table II-1. PID VOC Sensor Calibration Summary

Trial	Test concentration (ppm)	K	Slope (1st order model	Slope (intercept = 0)	Slope (ppbPRO)	PID Sensor
Cal. 7	23.3	-0.0031	25.87	25.03	7.64	20
Cal. 8	23.3	-0.0031	24.99	24.61	7.93	20
Cal. 9	23.3	-0.0032	23.99	23.60	7.29	20
Cal. 10	23.3	-0.0031	25.31	25.00	7.58	20
Cal. 11	23.3	-0.0030	25.65	25.31	80.5	20
Cal. 12	23.3	-0.0032	24.08	23.92	7.87	20
Cal. 13	23.3	-0.0031	26.92	26.46	8.09	20

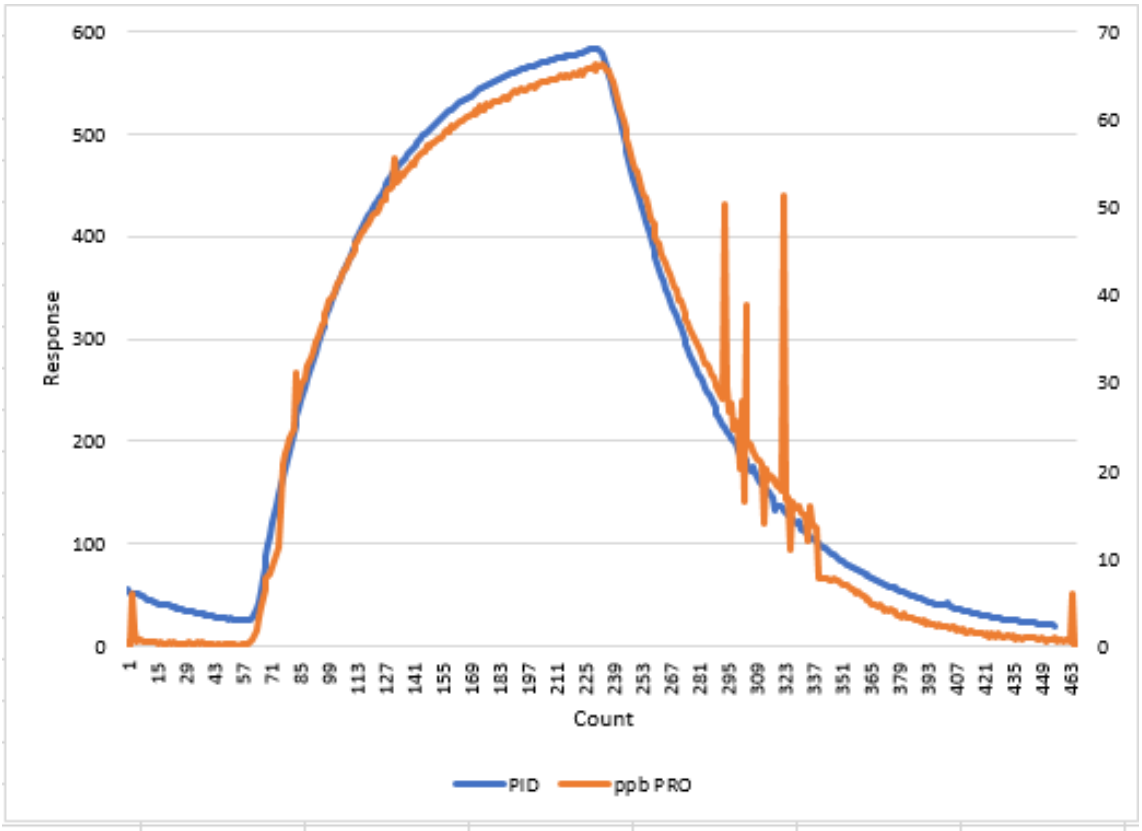

Figure II-2. Example graph of VOC PID Sensor and ppbPRO response over time for Calibration Trial 1

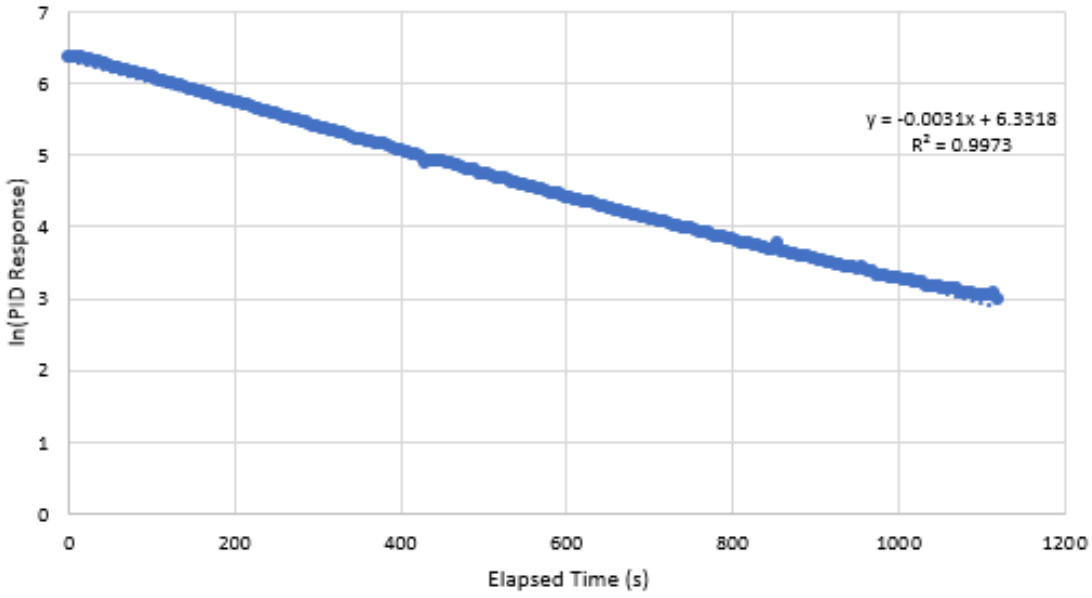

Figure II-3. Example graph of ln-transformed VOC PID Response over time for Calibration Trial 1

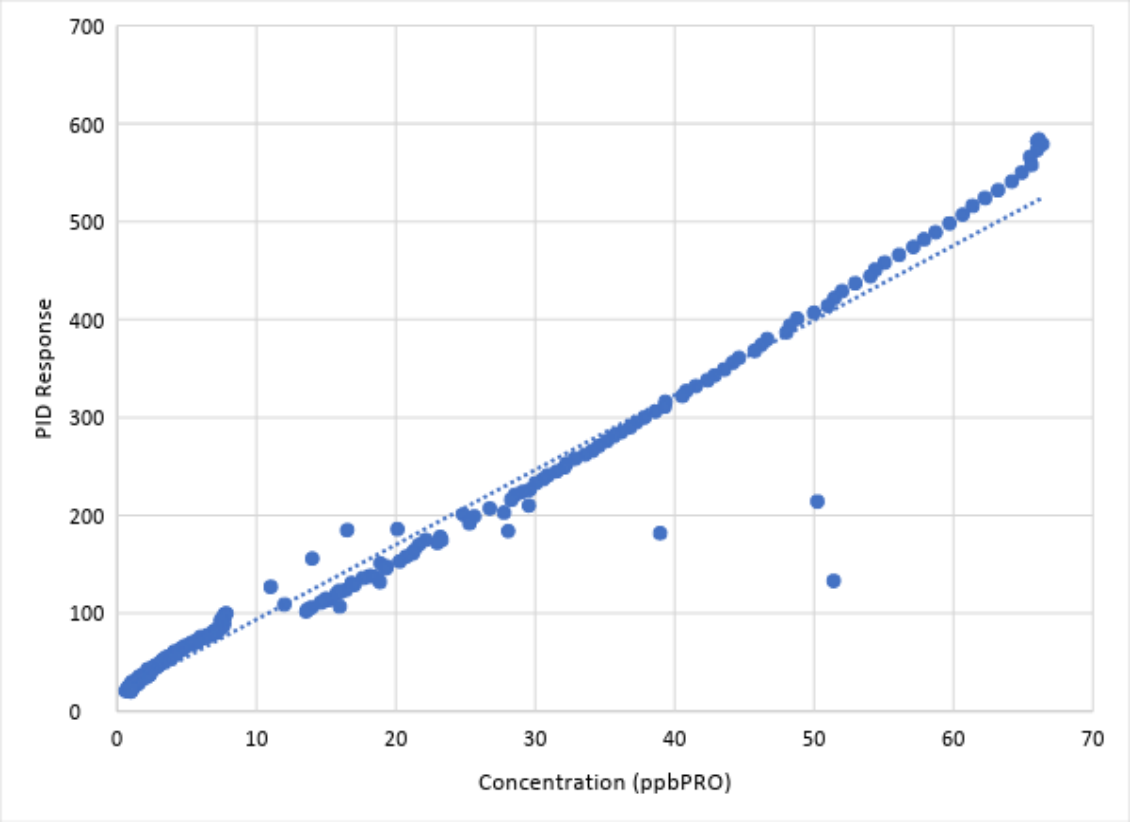

Figure II-4. Example graph of ppbPRO concentration versus VOC PID response for Calibration Trial 1

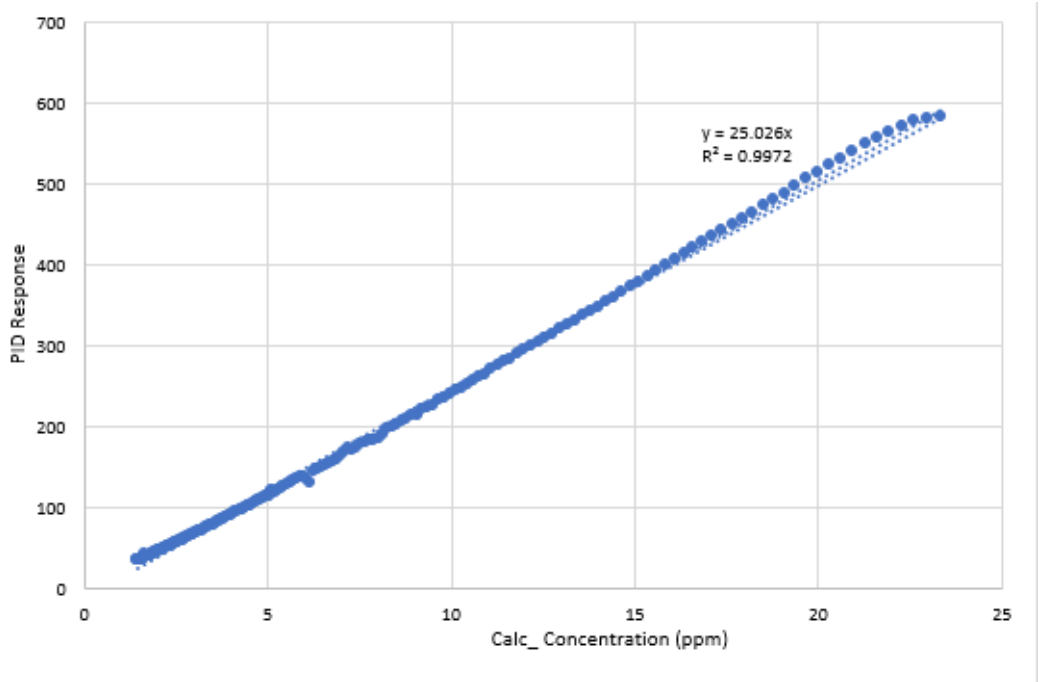

Figure II-5. Example graph of Calculated Concentration vs. VOC PID Response for Calibration Trial 1

Table II-2. List of 21 terpenes analyzed via GC/MS from sorbent tube sampling from December and January campaigns and associated QA/QC data from the extraction experiment

Terpene	Average Recovery (%)	Recovery RSD (%)	Limit of Detection (ng)
Alpha-pinene	80	10	25
Camphene	81	10	25
Sabinene	74	10	25
Beta-pinene	79	10	25
Beta-myrcene	62	12	50
p-mentha-1,5-diene	55	9	25
1(s)-(+)-3-carene	63	9	25
Alpha-terpinene	62	9	25
R(+) limonene	71	19	25
Ocimene Peak 1	63	11	100
Eucalyptol	76	14	50
Ocimene Peak 2	46	22	50
Gamma-terpinene	58	7	50
Terpinolene	44	27	100
(+) & L(-) fenchone	76	31	100
Isobomeol	99	7	250
Trans-caryophyllene	54	36	100
Alpha-cedrene	52	28	100
Alpha-humulene	63	11	100
Valencene	39	17	100
(+) cedrol	44	14	250

Table II-3. Sorbent tube data flags, flag description and resulting action

Flag Code	Description	Action
1	Sample is above upper quantification limit	Delete value/censor value cell
2	Sample is below the lower limit of detection (LLOD)	Add flag code, no change to value
3	Sample tube overloaded, mass on back half of sorbent tube is greater than 10% of the mass from the front half	No samples determined to meet criteria
4	Change in the flow rate exceeded 10%	No samples determined to meet criteria
5	Corrected during quantification by internal standard	Add flag code, no change to value

Table II-4. Shapiro-Wilk Assessment of Log-normality (p-value < 0.05 suggests that distribution of data does not follow typical assumptions of normality)

Sample Type	P-Value
PNC	0.5511
PMC	< 0.001
Terpene Mass Concentration	<0.001

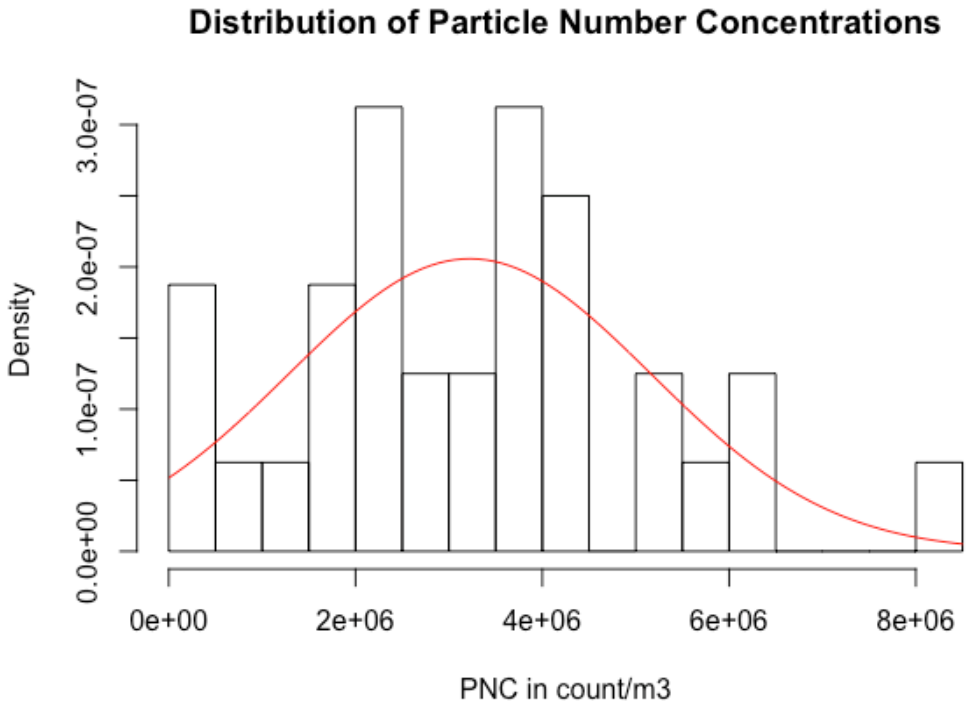

Figure II-6. Assessment of normality: distribution of particle number concentrations (PNCs)

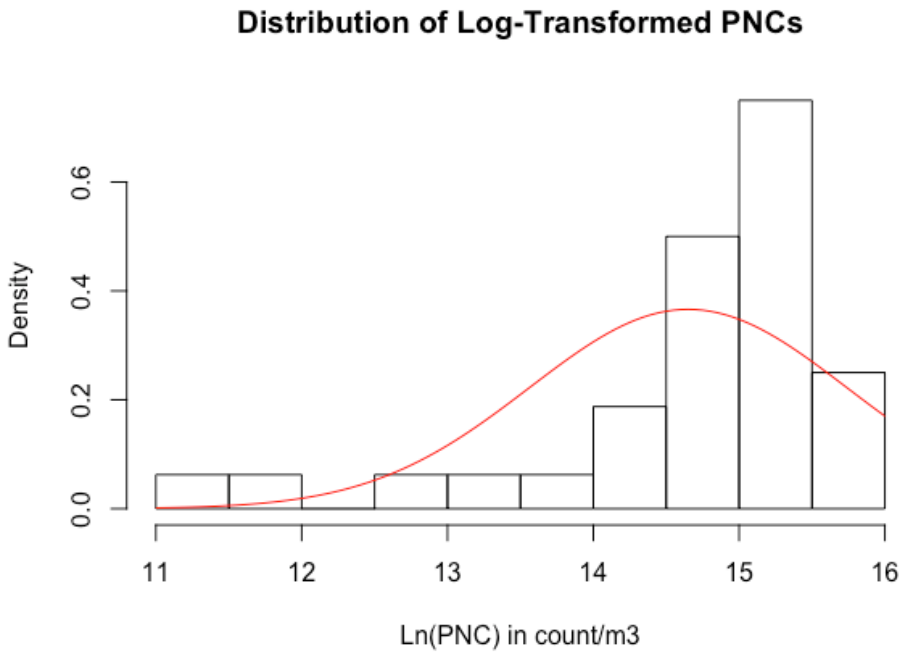

Figure II-7. Assessment of log-normality: distribution of natural log transformed particle number concentrations (PNCs)

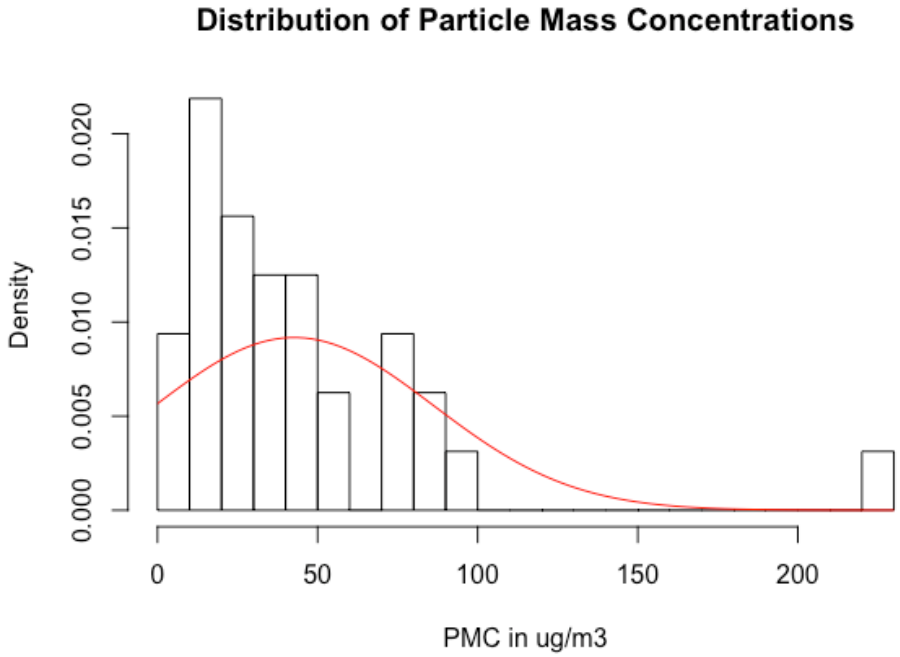

Figure II-8. Assessment of normality: distribution of particle mass concentrations (PMCs)

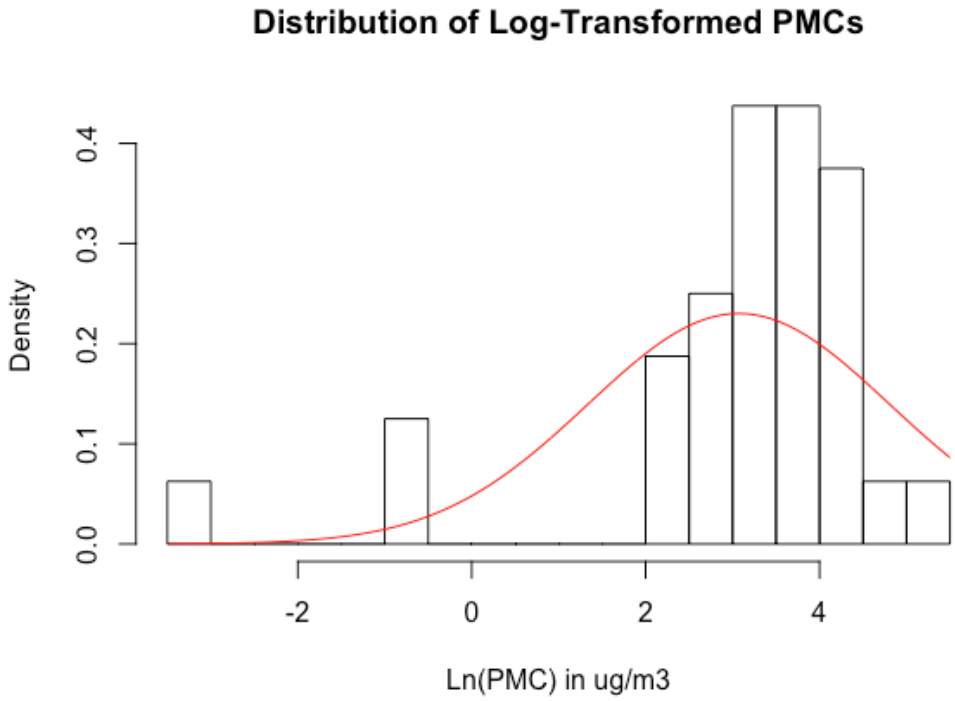

Figure II-9. Assessment of log-normality: distribution of natural log transformed particle mass concentrations (PMCs)

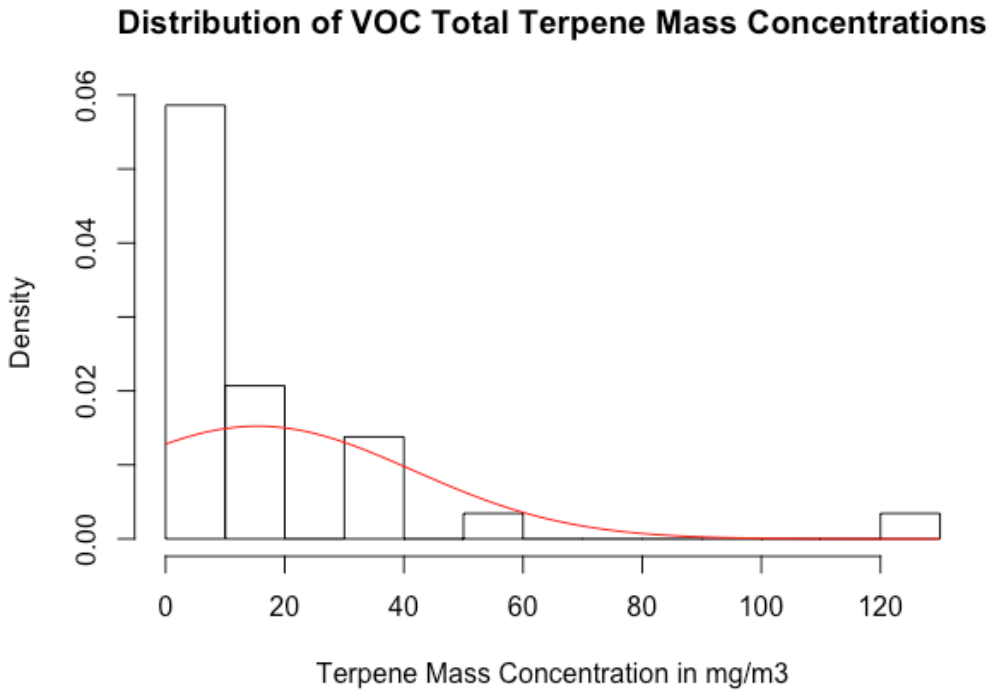

Figure II-10. Assessment of normality: distribution of total terpene mass concentrations

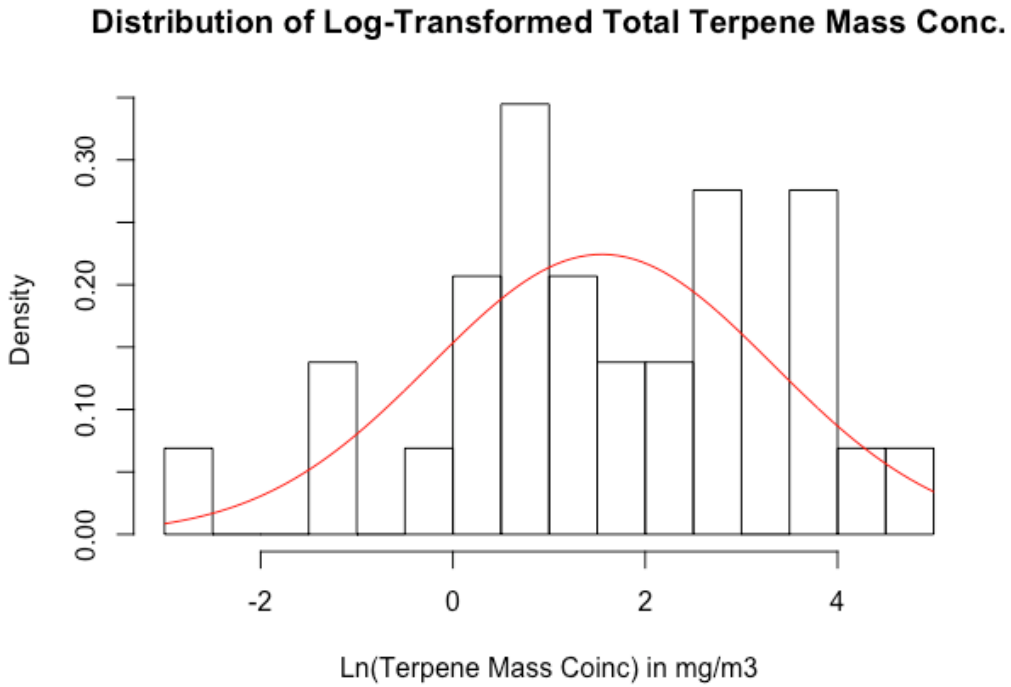

Figure II-11. Assessment of log-normality: distribution of natural log transformed total terpene mass concentrations

Appendix III. – Results: Supplementary Tables and Figures

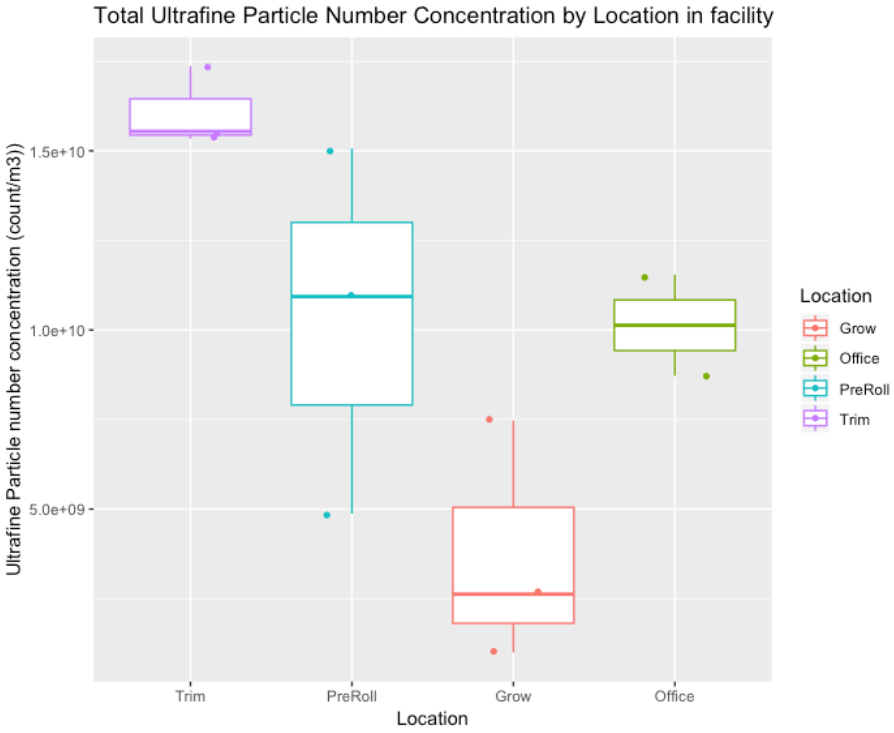

Figure III-1. Ultrafine PNC (count/m^3) by task area from P-Trak Ultrafine Particle Counter

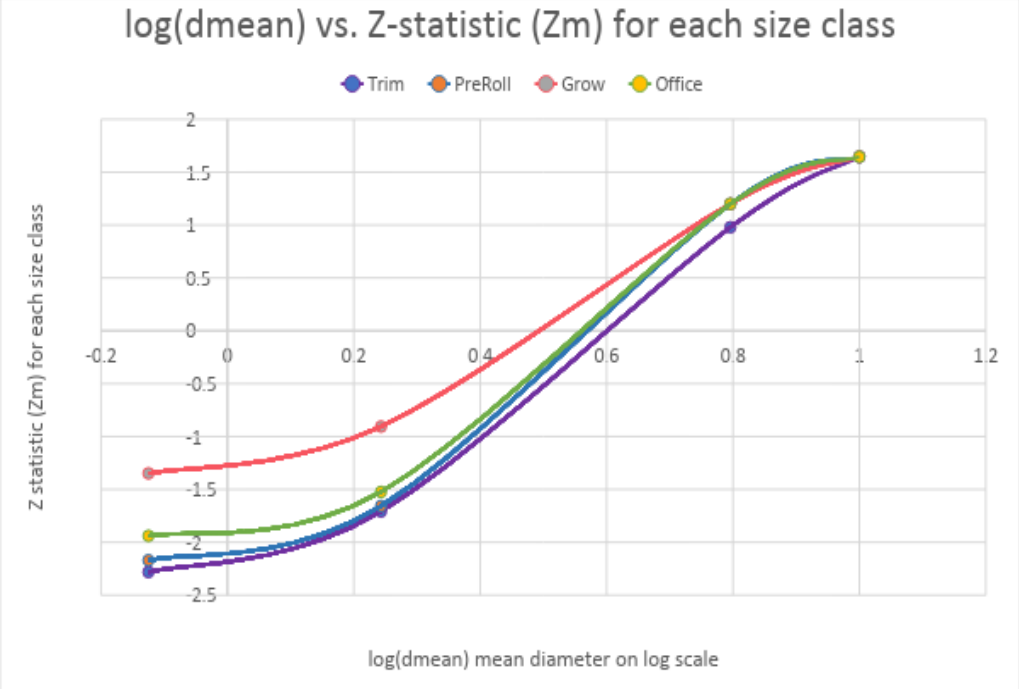

Figure III-2. Log-transformed mean diameter of the Dylos size bins compared to the z-statistic for each size class

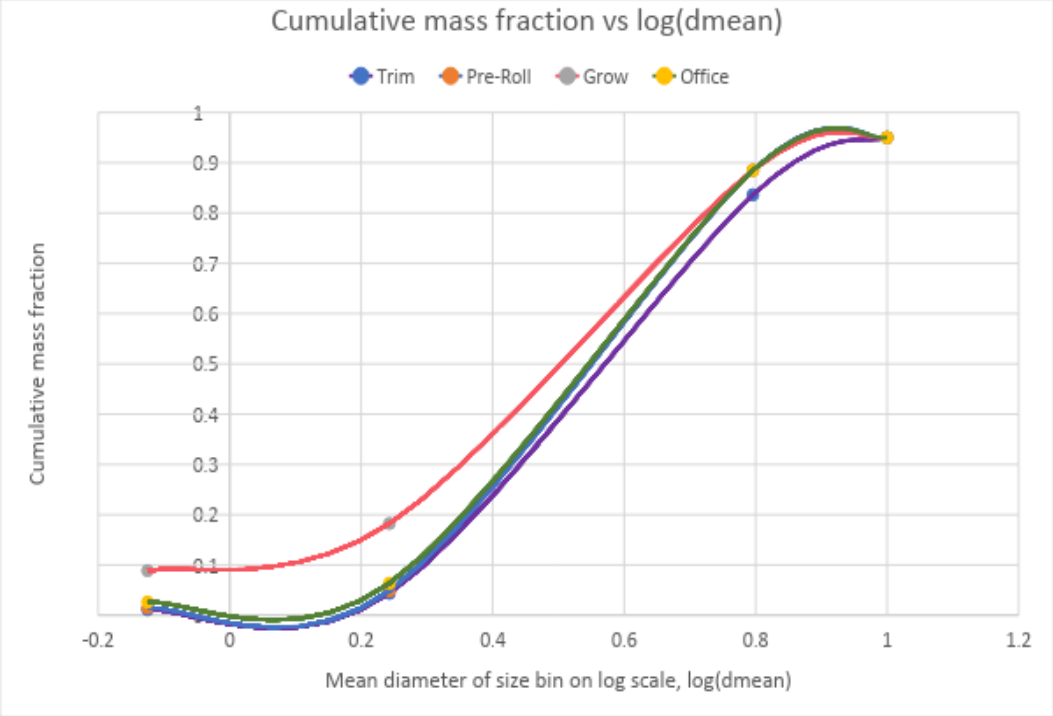

Figure III-3. Cumulative mass fraction of data based on log-transformed diameter of Dylos size bins

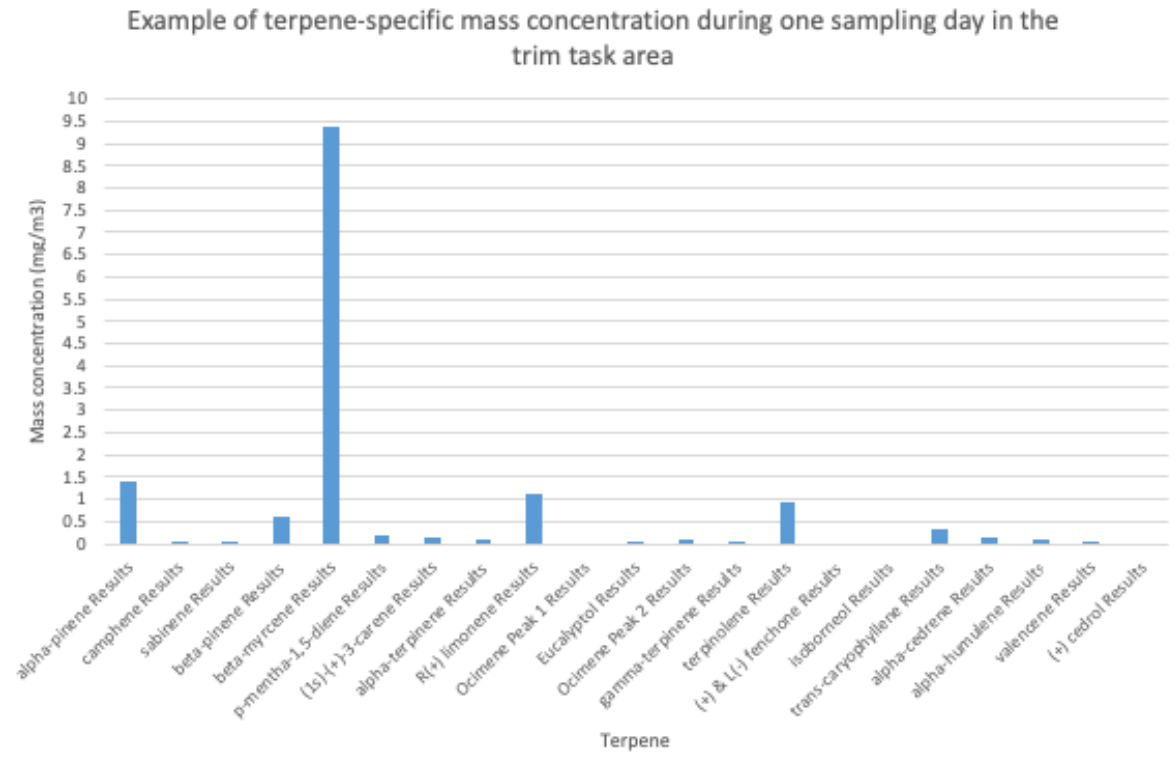

Figure III-4. Example of a single day sampling results of the mass concentrations of each of the 21 specific terpenes analyzed using GC/MS

Appendix IV. – Daily worker task observations

Table V-1. Worker task observations of sampling day 1, December 3, 2018

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	No employees working in trim task area
10:00 am – 12:00 pm	1 worker at mechanical grinding/sifting station
12:30 pm – 2:00 pm	1 worker at mechanical grinding/sifting station, 1 worker at shaker table
2:00 pm – 4:00 pm	1 worker at mechanical grinding/sifting station, 1 worker at shaker table
Pre-Roll Task Area	
8:00 am – 10:00 am	7 workers processing joints (packing joint cones with coarse cannabis powder) at North end Table
10:00 am – 12:00 pm	7 workers processing joints at North-End table, 3 workers processing joints at South-end table and placing finishing joints into packing and applying labels
12:30 pm – 2:00 pm	Same as before, 1 additional worker now processing at South-end table
2:00 pm – 4:00 pm	Same as before
Grow Task Area	
8:00 am – 10:00 am	Workers are harvesting the end-stage grow room, 3 workers are cutting down plants in far-end of the room and transferring the plants to large black buckets
10:00 am – 12:00 pm	3 workers continue to harvest moving from far-end of grow room towards entrance door
12:30 pm – 2:00 pm	Harvest of the grow room is completed by the lunch break, 2 workers are sweeping the empty room and removing potting bags and placing into the large black tubs
2:00 pm – 4:00 pm	1 worker continues to clear grow room by sweeping the floors and the plant trays and manipulating the movable plant trays

Table V-2. Worker task observations of sampling day 2, December 7, 2018

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	1 worker at mechanical grinding/sifting station, 1 worker at shaker table
10:00 am – 12:00 pm	1 worker at mechanical grinding/sifting station, 1 worker at shaker table
12:30 pm – 2:00 pm	1 worker at mechanical grinding/sifting station, 1 worker at shaker table
2:00 pm – 4:00 pm	1 worker at shaker table until approx. 3:00 pm, 2 workers at shaker table until end of work day
Pre-Roll Task Area	
8:00 am – 10:00 am	5 workers processing joints (packing joint cones with coarse cannabis powder) at North end Table
10:00 am – 12:00 pm	5 workers processing joints at North-End table
12:30 pm – 2:00 pm	1 worker continued processing joints during 30-minute lunch break, 7 workers processing joints at North-End table, 5 workers on South-end table completing tasks split between pre-rolling/processing joints and applying packaging and labels to the completed joints
2:00 pm – 4:00 pm	Same as before, 8 workers working between both tables
Grow Task Area	
8:00 am – 10:00 am	2 workers in grow room, 1 worker trimming plants for first hour of day
10:00 am – 12:00 pm	1 worker in grow room labeling plants
12:30 pm – 2:00 pm	Vacant room
2:00 pm – 4:00 pm	Vacant room

Table V-3. Worker task observations of sampling day 3, December 10, 2018

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	1 worker at mechanical grinding/sifting station, 1 worker at shaker table
10:00 am – 12:00 pm	Same as before
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Pre-Roll Task Area	
8:00 am – 10:00 am	7 workers processing joints (packing joint cones with coarse cannabis powder) at North end Table for 1 hour 8 workers processing/rolling joints at North-end table, 4 workers rolling joints at south-end table for 2nd hour
10:00 am – 12:00 pm	Same as before, but 2 of the 4 workers at the south-end table are packaging the joints
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	9 workers at North-end table processing/rolling joints, 2 workers at south-end table weighing buds and packaging into clear mason jars
Grow Task Area	
8:00 am – 10:00 am	Monitors set up in mid-stage grow room, no workers occupying room
10:00 am – 12:00 pm	1 worker labeling and trimming plants at far-end of the room
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Vacant room

Table V-4. Worker task observations of sampling day 4, December 14, 2018

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	7 workers hand trimming and sorting bud
10:00 am – 12:00 pm	6 workers hand trimming and sorting bud
12:30 pm – 2:00 pm	7 workers hand trimming and sorting bud, 1 worker at mechanical trim/sifting table
2:00 pm – 4:00 pm	Same as before
Pre-Roll Task Area	
8:00 am – 10:00 am	3 workers packaging buds/flower into plastic bags, 1 worker adding package labels
10:00 am – 12:00 pm	6 workers packaging bud and placing labels on the package
12:30 pm – 2:00 pm	4 workers placing labels on packages (workers no longer handling bud/flower)
2:00 pm – 4:00 pm	3 workers in pre-roll area hand trimming and packaging bud
Grow Task Area	
8:00 am – 10:00 am	1 worker at far-end of grow room pruning plants
10:00 am – 12:00 pm	Same as before
12:30 pm – 2:00 pm	Single worker pruning plants towards the front-end (entrance to the grow room where monitors are located)
2:00 pm – 4:00 pm	Same as before

Table V-5. Worker task observations of sampling day 5, January 14, 2019

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	No trim activities occurring, results from monitors may show baseline air contaminant levels
10:00 am – 12:00 pm	1 worker at sifting/blending table
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Pre-Roll Task Area	
8:00 am – 10:00 am	4 workers rolling and packaging joints, 3 workers cleaning glass jars
10:00 am – 12:00 pm	Same as before
12:30 pm – 2:00 pm	8 workers cleaning and labeling glass jars for packaging
2:00 pm – 4:00 pm	Same as before
Grow Task Area	
8:00 am – 10:00 am	2 workers harvesting plants
10:00 am – 12:00 pm	Plants removed from grow room, 2 workers removing plots from empty grow room
12:30 pm – 2:00 pm	1 worker tidying wires in empty grow room and vacuuming
2:00 pm – 4:00 pm	Same as before

Table V-6. Worker task observations of sampling day 6, January 18, 2019

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	1 worker at shaker table
10:00 am – 12:00 pm	Same as before
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Pre-Roll Task Area	
8:00 am – 10:00 am	9 workers processing/rolling joints
10:00 am – 12:00 pm	8 workers processing joints, 2 workers packaging and labeling joints into plastic bags
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Grow Task Area	
8:00 am – 10:00 am	2 workers watering and trimming plants
10:00 am – 12:00 pm	3 workers transferring plants from elevated table to rolling rack with 3 tiers, and then moving the tiers to the mid-stage grow room across the hallway
12:30 pm – 2:00 pm	Same as before, half of the plants have been removed from the initial pre-flower room
2:00 pm – 4:00 pm	Few plants remain in pre-flower room, workers no longer completing tasks within the room

Table V-7. Worker task observations of sampling day 7, January 21, 2019

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	1 worker at shaker table
10:00 am – 12:00 pm	Same as before
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Pre-Roll Task Area	
8:00 am – 10:00 am	8 workers at North-end processing/rolling joints
10:00 am – 12:00 pm	6 workers at North-end table processing/rolling joints
12:30 pm – 2:00 pm	8 workers at North-end processing/rolling joints
2:00 pm – 4:00 pm	Same as before
Grow Task Area	
8:00 am – 10:00 am	2 workers in nursery room
10:00 am – 12:00 pm	Same as before
12:30 pm – 2:00 pm	3 workers transferring plants from tables in the nursery room to the pre-flower grow room via a 3 tier cart
2:00 pm – 4:00 pm	Vacant room, no workers

Table V-8. Worker task observations of sampling day 8, January 25, 2019

Time Period	Task description
Trim Task Area	
8:00 am – 10:00 am	3 workers hand trimming bud/flower, 1 worker at knock-box every 20 mins
10:00 am – 12:00 pm	Same as before, 1 worker now at shaker table
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Pre-Roll Task Area	
8:00 am – 10:00 am	4 workers pre-rolling joints at North-end table
10:00 am – 12:00 pm	4 workers processing/rolling joints at North-end table, 1 worker placing finished joints in plastic packaging
12:30 pm – 2:00 pm	Same as before
2:00 pm – 4:00 pm	Same as before
Grow Task Area	
8:00 am – 10:00 am	2 workers transplanting plants in nursery into larger pots, 1 worker watering and trimming existing plants
10:00 am – 12:00 pm	4 workers transplanting plants in nursery into larger pots, 1 worker watering and trimming existing plants
12:30 pm – 2:00 pm	Vacant room, no workers
2:00 pm – 4:00 pm	Vacant room, no workers