Annals of Work Exposures and Health, 2020, 64, No. 7, 754–764
doi: 10.1093/annweh/wxaa050
Advance Access publication 27 May 2020
Original Article

Original Article

Allergic and Respiratory Symptoms in Employees of Indoor *Cannabis* Grow Facilities

Coralynn Sack[1,2,*], Niloufar Ghodsian[1], Karen Jansen[1], Brynne Silvey[1] and Christopher D. Simpson[1]

[1]Department of Environmental and Occupational Health Sciences, University of Washington, 1959 NE Pacific Street, Seattle, WA 98195, USA; [2]Department of Medicine, University of Washington, 1959 NE Pacific Street, Seattle, WA 98195, USA

*Author to whom correspondence should be addressed. Tel: 206-543-1520; e-mail: cssack@uw.edu

Submitted 11 September 2019; revised 1 April 2020; editorial decision 21 April 2020; revised version accepted 28 April 2020.

Abstract

Background: While little is known about the occupational hazards associated with *Cannabis* cultivation, both historical research in the hemp industry and preliminary data from modern grow houses, suggest that *Cannabis* workers may be at increased risk of respiratory and allergic diseases.
Objectives: We sought to investigate the association between workplace exposures and health symptoms in an indoor *Cannabis* grow facility in Washington State, USA.
Methods: We performed a cross-sectional study with all consenting employees in an indoor *Cannabis* grow facility in Seattle, WA using a questionnaire. The questionnaire gathered data on respiratory, ocular, nasal, and dermal symptoms. A subset of employees with work-related symptoms underwent repeated cross-shift and cross-week measurement of spirometry, fractional exhaled nitrogen oxide (FeNO), and skin prick testing for *Cannabis* sensitization. Exposure to *Cannabis* dust was classified based on self-described tasks, expert opinion, and exposure monitoring of particulate matter. Multivariable logistic regression was undertaken to examine associations between exposure to *Cannabis* dust (classified as low, medium, and high) and health symptoms. Linear mixed effects models examined the relationship between cross-shift and cross-week changes in spirometry and FeNO.
Results: Ninety-seven percent (97%) of the employees ($n = 31$) surveyed were recreational cannabis users, with 81% ($n = 25$) smoking cannabis multiple times per day. Twenty-two (71%) employees reported one or more work-related symptoms: 65% respiratory, 39% ocular, 32% nasal, and 26% dermal symptoms. There was a trend toward increased likelihood of work-related symptoms with increasing exposure to *Cannabis* dust, although none of these results were statistically significant. Of the 10 employees with work-aggravated symptoms, 5 had borderline-high or high FeNO, 7 had abnormal spirometry, and 5 had evidence of *Cannabis* sensitization on skin prick testing. FeNO increased by 3.78 ppb (95% confidence interval 0.68–6.88 ppb) across the work-week and there was a trend toward cross-week and cross-shift reduced airflow.

Conclusions: We found a high prevalence of work-related allergic- and particularly respiratory symptoms in the employees of one indoor *Cannabis* grow facility in Washington State. A high proportion of employees with work-aggravated symptoms had findings consistent with probable work-related asthma based on high FeNO, airflow obstruction on spirometry, and *Cannabis* sensitization on skin prick testing. However, due to the high incidence of recreational cannabis use among these workers, the relative influence of occupational versus recreational exposure to *Cannabis* dust on the respiratory health and sensitization status of these workers could not be resolved in this study.

Keywords: allergic disease; *Cannabis*; occupational asthma; occupational hazards; respiratory symptoms

Introduction

Very little is known about the occupational hazards associated with cultivation of *Cannabis* for medicinal or recreational use given its recent status as an illegal drug. While still considered a Schedule 1 drug by the US Federal government, 33 states and the District of Columbia have legalized marijuana in some form (Steigerwald *et al.*, 2019). This has led to the rapid expansion of the recreational and medicinal *Cannabis* industry with thousands of new employees joining the workforce each year (Cox, 2019). Given this fast growth, there is some urgency in understanding the potential health consequences of occupational exposure to *Cannabis* for those working in the industry.

While the *Cannabis* plant can be grown outdoors, indoor grow facilities are common due to increased crop productivity, higher-quality product, and improved crop security (Martyny *et al.*, 2013). Cultivation within indoor greenhouses is a highly regulated process with close control of light, humidity, and temperature to regulate the life cycle of the plant and maximize crop yield. While outdoor farms are typically able to harvest only once a season, indoor facilities can harvest up to three or four times per year. In contrast with many other agricultural processes, cultivation of *Cannabis* for recreational and medicinal use involves substantial manual labor, which means that workers spend a significant amount of time handling the plant during harvesting, trimming, and preparation of dried product (Butsic and Brenner, 2016).

The Colorado Department of Public Health and Environment recently released a 'best practices' guide for worker health and safety in the recreational marijuana industry (Marijuana Occupational Health and Safety Work Group, 2017). This guidance was based on expert judgment of knowledgeable health and safety professionals from government agencies and research institutes, who conducted walkthrough evaluations of *Cannabis* grow operations, but did not include any measurements of exposure or health outcomes. The report identified a range of biological, chemical, and physical health hazards. In particular, the report cited significant concern for potential hazardous respiratory exposures, including pesticides, molds, endotoxins, volatile organic compounds (VOCs), and particulate matter (PM). In addition to the findings in this report, a recent National Institute for Occupational Safety and Health (NIOSH) health hazard evaluation in a grow facility in Minnesota also reported diacetyl and 2,3-pentedione in screening air samples (Couch *et al.*, 2019).

What is known about occupational health effects in the recreational and medicinal *Cannabis* industry is largely inferred from studies of hop production and the hemp textile market in the late 20th century (Davidson *et al.*, 2018). The hop plant, *Humulus lupulus*, is from the same family as the *Cannabis* plant, *Cannabaceae*. Hemp is derived from the same plant genus and species as recreational marijuana, *Cannabis sativa*, but has been bred to produce fiber rather than tetrahydrocannabinol, the psychoactive component of *Cannabis*. Epidemiology studies in both the hemp and hop industries report a high rate of respiratory illnesses, including byssinosis, chronic bronchitis, reactive airways dysfunction syndrome, and asthma (Zuskin *et al.*, 1990; Reeb-Whitaker and Bonauto, 2014; Er *et al.*, 2016). There have also been a few published studies of workers in forensic laboratories, law enforcement officers dismantling illegal grows, and employees of recreational *Cannabis* facilities (Williams *et al.*, 2008; Herzinger *et al.*, 2011; Victory *et al.*, 2018; Decuyper *et al.*, 2019b). These raise concern for allergic symptoms, including eye irritation, nasal congestion, hand eczema, and asthma.

The purpose of the current study was to investigate the association between workplace exposures and allergic and respiratory symptoms in an indoor recreational *Cannabis* grow facility in Washington State.

Methods

Study design and population

To explore the association between occupational exposures and allergic symptoms in *Cannabis* workers at an indoor grow facility, the study had two main components: (i) a cross-sectional study of self-reported respiratory, ocular, nasal, and dermal symptoms in *Cannabis* employees in relation to occupational dust exposure and (ii) a repeated measurements study of health effects in a cohort of employees with self-reported work-related symptoms (see Fig. 1).

For the cross-sectional study, all 45 workers that were currently employed at the indoor grow facility were eligible for enrollment and completion of the health questionnaire. Ten of the employees who reported work-related symptoms on questionnaire were recruited for the repeated measurements study (see Supplementary Fig. S1, available at *Annals of Work Exposures and Health* online). These selected employees were followed for a period of 2 weeks with repeat measurements of spirometry, fractional exhaled nitric oxide (FeNO), postshift symptom questionnaires and on one instance, skin prick testing.

The study was reviewed and approved by the University of Washington Institutional Review Board and participants gave written consent.

Location

The study was conducted in an indoor *Cannabis* producer/processor facility in Washington State from October 2018 through January 2019. This facility operates under a Tier three license, the largest size category (defined by 10 000–30 000 square feet of plant canopy), and uses conventional (nonorganic) cultivation methods. A workforce of approximately 45 full time employees is employed at the facility (Washington State Liquor and Cannabis Board, 2019). Process operations include drying plant material, removing the inflorescences (commonly referred to in industry as 'buds') from the dry plants, trimming and packing of intact 'buds' for sale; crushing plant material for use in smoking products; packing the plant matter into smoking products; extracting plant material using propane extraction or thermal expeller techniques to make cannabis concentrates, and distillation of cannabis extract. In addition to growing their own product, the facility seasonally purchases outdoor-grown *Cannabis* from other growers in the region, which they then process into consumer products (buds, cigarettes, and cannabis extracts and distillates).

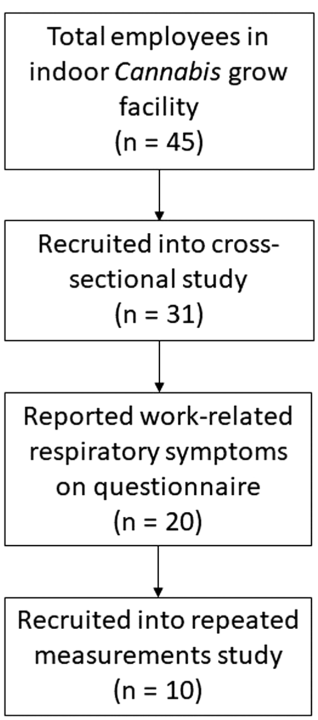

Figure 1. Number of study participants recruited into the (i) cross-sectional study and (ii) repeated measurements study.

Baseline questionnaire

As part of the cross-sectional study, a questionnaire was adapted from the European Community Respiratory Health Survey and administered to all consenting employees in the indoor *Cannabis* grow facility (Burney *et al.*, 1994). In addition to basic sociodemographic information, the questionnaire included occupational history, detailed personal tobacco, and cannabis use history, typically performed work tasks, use of personal protective equipment (PPE), and presence of work-related health symptoms (see Appendix II: Baseline Questionnaire, available at *Annals of Work Exposures and Health* online). Work-related symptoms were considered present if the subject answered positively to question(s) such as 'do you develop symptoms when you are at work', 'does contact with certain materials, chemicals or anything else in your work makes your symptoms worse?', or 'do your symptoms improve when you are away from your normal work?'

Repeated health measurements

Employees enrolled in the repeat measurements component of the study were followed during December 2018 and January 2019. Study visits occurred on Mondays and Fridays, for a total of up to four work shifts monitored per subject. FeNO and spirometry measurements were taken both pre- and postshift; skin prick testing for *Cannabis* sensitization was performed on one occasion.

Fractional exhaled nitric oxide

Airway inflammation was determined by measurement of FeNO in compliance with American Thoracic

Society (ATS)/ERS recommendations ('ATS/ERS recommendations for standardized procedures for the online and offline measurement of exhaled lower respiratory nitric oxide and nasal nitric oxide, 2005,' 2005). Measurements were taken by a trained technician using a chemiluminescence analyzer, NIOX VERO (Morrisville, NC, USA) and expressed in parts per billion (ppb). Abnormal or borderline FeNO was defined according to ATS criteria: <25 ppb normal, 25–50 ppb borderline, and >50 ppb abnormal (Dweik *et al.*, 2011).

Spirometry

Spirometry was conducted with participants in the seated position using a NDD EasyOne Air portable spirometer (Andover, MA, USA). The test was done a minimum of three acceptable times and repeatability was verified according to STS/ERS guidelines (Miller *et al.*, 2005). Forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), and the FEV_1/FVC ratio were used for analysis. Results were expressed as a percentage of the predicted values given by National Health and Nutrition Examination Survey (NHANES) III reference equation (Hankinson *et al.*, 1999). For interpretation a fixed cutoff of 80% of predicted was used to define normal. Pulmonary airway disturbances were classified as follows: (i) obstructive—FEV_1/FVC below 0.70; (ii) restrictive—FEV_1 and/or FVC below 80% with a FEV_1/FVC equal or above 0.70; and (iii) mixed—FEV_1 and FVC below 80% with a FEV_1/FVC below 0.70 (Pellegrino *et al.*, 2005).

Skin prick test

A one-time skin prick test was performed on each employee to *Cannabis* and selected mold species found in the Pacific Northwest region of the USA. Mold extracts were purchased from ALK-Abello, Inc. (Round Rock, TX, USA) and consisted of *Helminthosporium*, *Alternaria*, *Penicillium*, and *Aspergillus*. *Cannabis* slurries were prepared using two strains of *Cannabis* grown at the facility. For each strain, a mixture of leaves and flowers were ground to make a fine powder and mixed with 1–2 ml of sterilized saline. A 10% histamine solution was used as a positive control and sterilized saline solution was used as a negative control. The largest wheal diameter was assessed 20 min after application on the forearm. A positive response was defined as a wheal diameter greater than or equal to 3 mm, erythema or pseudopodia with no reaction to the negative control and positive reaction to histamine.

Daily questionnaire

On each day of data collection, a short questionnaire was also administered to each study subject at the end of the shift. Participants recorded tobacco and cannabis use within the last 24 h, work tasks and health symptoms during the past shift.

Statistical analysis

Statistical tests were performed in SAS version 9.3 (SAS Institute) or R (R Core Team) (Team, 2015) using a two-tailed *P* value with α = 0.05 to define statistical significance.

Occupational exposure to *Cannabis* was defined according to self-reported task on questionnaires. Participants reported approximately 24 different tasks (Supplementary Table S2, available at *Annals of Work Exposures and Health* online) that were categorized into three main exposure categories: low, medium, and high (see Table 1). Category assignment was based on observation, discussions with facility management/employees and monitoring of PM/VOCs performed for a complementary study. Dust-generating tasks such as sifting and grinding were placed into the high exposure category, whereas office tasks with low dust exposure were assigned to the low exposure category. In the complementary study by Silvey *et al.*, airborne dust concentrations, measured using a Dylos 110 Pro optical particle counter (Riverside, CA, USA), were the lowest for office task zones, 18.5 [interquartile range (IQ) = 13.8–21.1] µg m^{-3}, and the highest for trim task zones, 59.2 [interquartile range (IQR = 43.5–78.2) µg m^{-3}. The trend was the same for VOC terpene mass concentrations (Silvey, 2019).

For each employee, the percentage of time spent on each job duty was determined by self-report on the baseline questionnaire. As employees typically performed multiple tasks per day, they were assigned an exposure category based on the majority of time (>50%) spent in any one exposure category.

Multivariable logistic regression was used to examine the association between occupational exposure to *Cannabis* (low, medium, and high; see Table 1) and self-reported work-related dermal, ocular, nasal, and respiratory symptoms. A staged approach to confounding was applied with (i) unadjusted base model and (ii) adjusted

Table 1. Categorization of *Cannabis* exposure by task.

Low	Medium	High
Office	Packing	Sifting
Order fulfillment	Weighing	Grinding
Sanitation	Hand-trimming	Knock box
Labeling	Preroll	Sorting/grading
	Spinning	Harvesting
	Nursery	
	Spraying	

for age, gender, and smoking status (current versus former/never) (McNamee, 2005). Linear mixed models were used to analyze repeated health measures (FEV_1, FVC, and FeNO) with fixed effects for cross-shift and cross-week exposures and random effect for individual.

Results

Baseline sociodemographic characteristics in individuals who underwent health effects testing (n = 10) were similar to the overall cohort of employees at the indoor cannabis grow operation (n = 31) (see Table 2). The mean age of employees at the facility was 31 years [standard deviation (SD) 7.7] and 19 (61%) individuals were male. Eight (26%) individuals had a preexisting diagnosis of asthma. Of the cohort, 10 (32%) employees reported current tobacco use, while 30 (97%) reported current cannabis use with 81% smoking cannabis multiple times per day. More detailed information about self-reported cannabis use is found in Supplementary Table S1, available at *Annals of Work Exposures and Health* online.

Job characteristics

Employees had worked at the *Cannabis* grow facility on average for 1.2 years (range 14 days to 4 years) and typically worked a 40-h week (see Table 3). A significant portion of employees (55%) had held a prior job within the *Cannabis* industry. A more detailed description of job duties and tasks is found in Supplementary Table S2, available at *Annals of Work Exposures and Health* online. While all employees reported performing multiple tasks per day, 30 (97%) of subjects spent at least 50% of their time performing tasks that had been assigned to a single exposure category (data not shown). Based on the distribution of tasks, 11 employees were assigned to the low *Cannabis* dust exposure category, 16 to medium, and 4 to high. Most employees wore some form of PPE, with 17 (55%) wearing respiratory protection in the form of a dust mask (occasional N95) or cartridge respirator. Respiratory PPE use was voluntary and there was no specific respirator training program implemented or fit testing performed in the facility.

Allergic and respiratory symptoms

Twenty-two (71%) employees surveyed reported work-related symptoms and 29 (94%) reported having overall health symptoms (see Fig. 1). Based on European Community Respiratory Health Survey definition of asthma (presence of either an attack of shortness of breath, an attack of asthma, or the use of asthma medication), 13 (42%) participants had symptoms suggestive of asthma (Pekkanen *et al*., 2005). A high proportion of workers reported work-related respiratory symptoms

Table 2. Participant demographics.

	All employees (n = 31)	Selected employees with work-related symptoms (n = 10)
Male (n, %)	19 (61)	7 (70)
Age (years, SD)	31 (7.7)	33 (11.8)
Caucasian (n, %)	23 (74)	8 (80)
Education level (n, %)		
≤ High school	9 (29)	2 (20)
Some college, no degree	9 (29)	3 (30)
≥ Bachelor's degree	13 (42)	5 (50)
Atopy (n, %)		
Asthma	8 (26)	3 (30)
Hay fever	8 (26)	4 (40)
Eczema	7 (23)	2 (20)
Tobacco use (n, %)		
Current	10 (32)	4 (40)
Past	10 (32)	1 (10)
Never	11 (35)	5 (50)
Cannabis use (n, %)		
Current	30 (97)	10 (100)
≥ Daily	26 (84)	9 (90)
Weekly	2 (6)	0
≤ Monthly	3 (10)	1 (10)

Table 3. Study demographics.

	All employees (*n* = 31)	Selected employees with work-related symptoms (*n* = 10)
Duration of current employment (years, range)	1.2 (0.04–4)	1.5 (0.04–4)
Hours per week (mean, SD)	43 (8.4)	43 (5.6)
Person protective equipment		
Gloves	28 (90%)	9 (90%)
Safety goggles	9 (29%)	2 (20%)
Dust mask	11 (35%)	3 (30%)
Cartridge respirator	7 (23%)	4 (40%)
Cannabis dust exposure (*n*, %)		
Low	11 (35%)	4 (40%)
Medium	16 (52%)	4 (40%)
High	4 (13%)	2 (10%)

(*n* = 20, 65%), including cough (*n* = 15, 48%), wheeze (*n* = 5, 16%), and chest tightness/shortness of breath (*n* = 8, 26%). Forty-five percent (*n* = 14) of study participants reported that symptoms improved on weekends and holidays, which further supports an association between occupational exposures and respiratory effects.

In addition to respiratory complaints, workers also reported work-related ocular (*n* = 12, 39%), nasal (*n* = 10, 32%), and dermal (*n* = 8, 26%) symptoms. When asked to identify the cause of work-related symptoms, participants most commonly identified *Cannabis*-associated components, such as *Cannabis* dust, kief (small organic crystals on the marijuana bud), terpenes, or particular plant strains. Other self-reported causes of symptom exacerbation included dust/PM, mold, soil, or pesticides.

There was a trend toward increased odds of work-related symptoms with increasing exposure to *Cannabis* dust, although none of these results were statistically significant (see Table 4). For example, compared with individuals with low *Cannabis* dust exposure, the odds of having work-related nasal symptoms was 1.6-fold higher [odds ratio (OR) 1.6, 95% confidence interval (CI) 0.27–11] and 2.5-fold higher (OR 2.5, 95% CI 0.19–37) in individuals with medium and high *Cannabis* dust exposure, respectively. A similar trend was observed for ocular and respiratory symptoms and remained consistent when adjusted for age, gender, and tobacco smoke. The effect of recreational cannabis use on these symptoms could not be determined because of the high prevalence (97%) of marijuana consumption in the worker population.

Health measurements

The health measurements in 10 participants with work-related symptoms are summarized in Table 5 and Fig. 2. Five (50%) of the 10 workers had borderline or abnormal FeNO, 7 (70%) had abnormal spirometry (5 with airflow obstruction, 1 with mixed pattern, and 1 with restriction). Five (50%) participants demonstrated *Cannabis* sensitization to one or more strains on skin prick testing. Of note, none of the participants exhibited sensitization to any of the molds tested. Based on the results of skin prick testing and spirometry, four of the five participants with *Cannabis* sensitization had possible immunologically mediated work-related asthma. The other individual with *Cannabis* sensitization had some evidence of airway inflammation with borderline FeNO (Malo and Vandenplas, 2011). None of the individuals with suspected work-related asthma had been previously diagnosed with asthma (Fig. 3).

Both cross-shift and cross-week measurements demonstrated a trend toward reduced airflow, with a cross-shift decline in FEV_1 of −7.8 ml (95% CI −23.3 to 7.7 ml; *P* = 0.29) and cross-week reduction of −1.7 ml (95% CI −17 to 14 ml; *P* = 0.81). While there was no evidence for a change in cross-shift FeNO, there was a significant increase in FeNO of 3.78 ppb (95% CI 0.68–6.88 ppb; *P* = 0.02) from Monday to Friday (see Table 6). Of note, other factors besides occupational exposures, such as smoking, can also effect FeNO. The majority of participants (9 out of 10) reported work-related symptoms after at least one of their shifts. There was no consistent relationship between self-reported tasks and postshift symptoms (data not shown).

Discussion

This study found a high prevalence of work-related allergic, and particularly respiratory, symptoms in the employees of one indoor *Cannabis* grow facility in Washington State. Among a group of 10 employees with work-aggravated symptoms, there was an increase in airway inflammation across the work-week and a trend

Table 4. Association between exposure to *Cannabis* dust and odds of work-related health symptoms.

Work-related symptom	Model	Exposure to *Cannabis* dust	OR (95% CI)
Dermal	Unadjusted	Medium	0.85 (0.14, 5.4)
		High	0.78 (0.031, 9.7)
	Adjusted	Medium	0.74 (0.075, 6.8)
		High	0.69 (0.019, 15)
Ocular	Unadjusted	Medium	1.6 (0.31, 9.5)
		High	8.0 (0.71, 203)
	Adjusted	Medium	3.4 (0.49, 35)
		High	18 (0.97, 760)
Nasal	Unadjusted	Medium	1.3 (0.25, 8.2)
		High	2.7 (0.23, 33)
	Adjusted	Medium	1.6 (0.27, 11)
		High	2.5 (0.19, 37)
Respiratory	Unadjusted	Medium	1.8 (0.37, 9.4)
		High	2.5 (0.23, 60)
	Adjusted	Medium	2.1 (0.40, 12)
		High	2.0 (0.16, 52)
Any	Unadjusted	Medium	1.0 (0.16, 6.0)
		High	1.1 (0.09, 28)
	Adjusted	Medium	1.1 (0.17, 7.4)
		High	0.72 (0.04, 20)

Cross-sectional association between exposure to *Cannabis* dust and the odds of work-related symptoms, from multivariable logistic regression unadjusted models and models adjusted for age, sex, and tobacco use. ORs are expressed in reference to the low *Cannabis* exposure category (OR 1).

Table 5. Health measurements in selected employees with work-related symptoms (n = 10).

FeNO, ppb (mean, range)	30 (8–102)
FEV_1 % predicted (mean, range)	89 (50–110)
FVC % predicted (mean, range)	96 (70–114)
FEV_1/FVC %, mean (range)	92 (54–111)
Restriction (n, %)	1 (10)
Obstruction (n, %)	5 (50)
Mixed (n, %)	1 (10)
Cannabis sensitization (n, %)	5 (50)

toward decreased cross-shift and cross-week spirometry. Furthermore, a significant portion of the employees with work-related symptoms had evidence of allergic sensitization to *Cannabis*, high FeNO and airflow obstruction on spirometry. This combination of features is suggestive of a diagnosis of immunologically mediated work-related asthma (Malo and Vandenplas, 2011).

This is one of a few studies that have evaluated occupational health effects in employees of *Cannabis* production facilities. A cross-sectional study of 214 Colorado *Cannabis* workers in indoor, outdoor, and greenhouse grow operations, found that employees reported skin irritation (n = 33, 17.6%), eye irritation (n = 25, 13.4%), difficulty breathing (n = 13, 7%), and chest discomfort (n = 11, 5.9%) after handling pesticides (Walters *et al.*, 2018). In a health hazard evaluation completed by NIOSH of nine employees at an indoor grow facility in Minnesota, 45% of employees noted that symptoms were aggravated at work. Only one participant had abnormal spirometry with a mildly restrictive pattern (Couch *et al.*, 2019). In contrast, 71% of employees in the current study reported work-exacerbated symptoms and 7 of 10 employees tested had abnormal lung function tests. The reasons for the much higher prevalence of symptoms and apparent disease in this population is unclear, but may be related to the small sample size, grow conditions in Washington, study protocol and questionnaire, or differences in employee characteristics, such as the high rate of recreational cannabis use. Of note, a similar high prevalence of work-related symptoms was also observed in another indoor grow facility in Washington (data unpublished).

The grow conditions required by the *Cannabis* plant result in many potential irritant and allergic hazards, including herbicides, molds, endotoxins, noxious gases, VOCs, and PM. Workers are exposed to carbon dioxide, carbon monoxide, pesticides, and other airborne contaminants common to agricultural-related industries (Donham

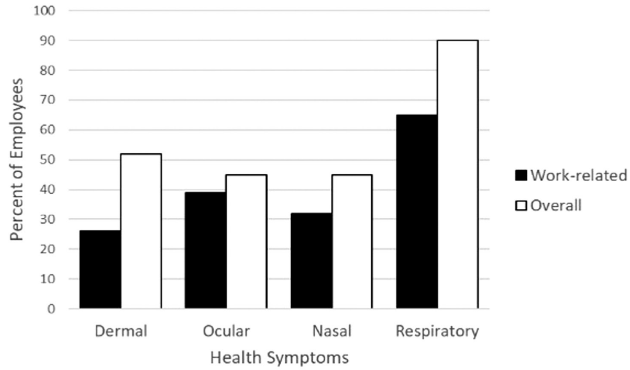

Figure 2. Prevalence of reported work-related and overall health symptoms in Cannabis workers (*n* = 31).

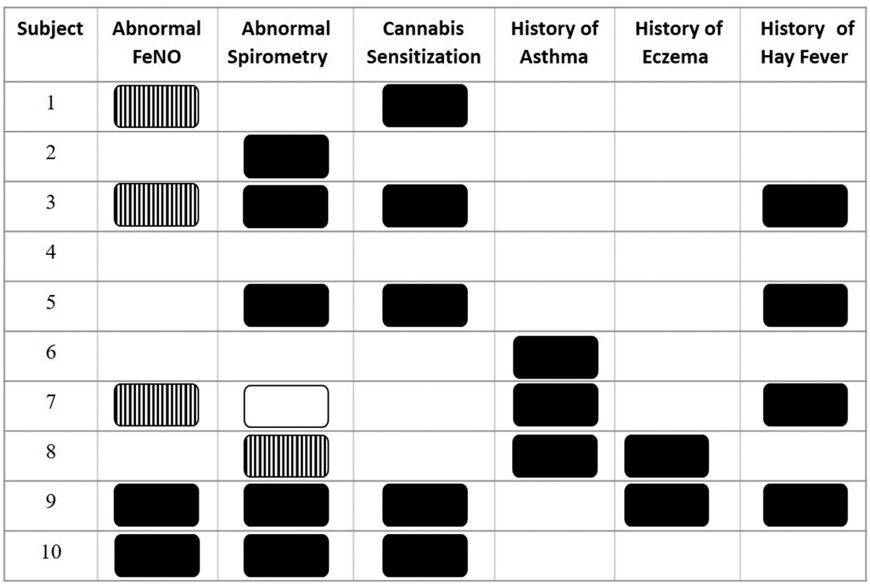

Figure 3. Summary of health measurements in selected employees with work-related symptoms. Solid color indicates abnormal fractional excretion of exhaled nitric oxide (FeNO >50 ppb), obstructive spirometry, or cannabis sensitization. Barred color for FeNO indicates borderline result of 25–50 ppb. Barred color for spirometry indicates mixed restrictive and obstructive ventilatory impairment, no fill indicates restrictive ventilatory impairment. All employees reported that they currently consumed cannabis recreationally.

Table 6. Cross-shift and cross-week changes in health measurements.

	Cross-shift change (95% CI)	Cross-week change (95% CI)
FeNO (ppb)	−1.36 (−4.46, 1.74)	3.78 (0.68, 6.88)***
FEV_1 (% predict)	−2.3 (−6.21, 1.58)	−0.16 (−4.06, 3.74)
FVC (% predict)	−0.83 (−2.64, 0.98)	−0.91 (−2.71, 0.90)
Ratio (% predict)	−1.60 (−5.17, 1.98)	0.39 (−3.19, 3.96)

Cross-shift (postshift minus preshift) and cross-week (Friday–Monday) change in FeNO, percent of predicted FEV_1, percent of predicted FVC, and percent predicted ratio of FEV_1/FVC (ratio), from linear mixed models with random effects for individual.
***Statistically significant result.

and Thelin, 2016). In particular, the sequential watering and drying of *Cannabis* plants leads to a significant amount of water vapor in indoor grow regions, providing an ideal environment for bacterial and fungal growth (Johnson and Miller, 2012; Martyny *et al*., 2013). The prolonged curing process, meant to remove excess moisture from the flowers after harvest, provides another opportunity for mold growth. Prior studies of *Cannabis* grow facilities have identified elevated levels of endotoxin and mold spores, including *Cladosporium* sp., *Penicillium* sp., and *Aspergillus* sp. (Martyny *et al*., 2013; Victory *et al*., 2018). The harvest and trimming phases of cannabis cultivation also release high concentrations of terpenes and other VOCs, which can act as respiratory irritants (Giese *et al*., 2015). While the levels of PM were relatively low at this facility (<0.1 mg m^{-3}), many of the tasks associated with *Cannabis* cultivation generate a significant amount of organic dust. Organic dust is a well-documented occupational hazard for those in several agriculture-related industries (Donham and Thelin, 2016). Determining which of these potential hazards is associated with health effects in *Cannabis* workers is important in designing work controls to protect employees.

The findings in this study suggest that *Cannabis* allergens may be a driving factor in the development of health symptoms due to a combination of recreational and occupational exposures. We found that 50% of workers tested had positive skin prick tests for *Cannabis* sensitization, while none had hypersensitivity to a panel of molds commonly found in the Pacific Northwest. Previous studies have documented that active and passive exposure to different members of the *Cannabacae* family can trigger sensitization (Decuyper et al., 2015, 2017). The resulting allergic manifestations can be mild to life threatening, including contact dermatitis, rhinitis, asthma, and angioedema (Silvers and Bernard, 2017). Researchers have isolated several *Cannabis* proteins that can lead to hypersensitivity, including nonspecific lipid transfer proteins, pathogenesis-related proteins, and an oxygen-evolving enhancer protein (Decuyper *et al*., 2018, 2019a). The prevalence of sensitization in those with either occupational or recreational exposure to cannabis is unknown. The results in this study warrant further evaluation to parse out when sensitization is occurring, and whether it correlates with onset of health symptoms. In addition, other potential occupational allergens warrant further investigation as there may be multiple causes of symptoms and potential risk to naïve workers with no previous *Cannabis* exposure.

Despite the high rate of observed *Cannabis* sensitization and employee concern that *Cannabis* dust was causing health effects, the study found no significant associations between assigned dust exposure and self-reported health symptoms or measurements. This may be attributable to a variety of factors, including the small study population, other unmeasured but contributory workplace exposures, recall bias of participants, or misclassification of *Cannabis* dust exposure. Exposure categorizations were predominantly based on observation by the study team rather than direct measurements and did not capture activities such as sweeping, which can generate acute exposure to high levels of airborne dust. Additionally, most employees performed multiple job duties within any given workday. Individuals performing job duties with low exposure to *Cannabis* dust, such as product inventory, were often in juxtaposition to employees performing high dust exposure tasks, such as preparing joints using the knock box. The relationship between *Cannabis* exposure and allergic sensitization has not been well described, and it is possible that high-dose acute exposures may be as important as chronic lower-dose exposures in causing adverse health effects.

There were several limitations to this study, reducing the generalizability of the reported findings. This was a small study of one indoor grow facility in Washington State with no control population for comparison. The repeated health measurements of the study were in a select group of workers with work-aggravated symptoms, and may not reflect the general population of employees. Almost all of the study participants were daily cannabis users, making it difficult to adjust for confounding by personal marijuana use. It is uncertain whether participants developed *Cannabis* sensitization from occupational versus recreational exposure. Regardless of the underlying route of sensitization, participants reported a high rate of work-aggravated symptoms, implying that occupational exposures to *Cannabis* or other workplace substances may have either caused or exacerbated health complaints.

Despite these limitations, the results of this study are provocative, demonstrating a high prevalence of recreational *Cannabis* use, work-related symptoms and probable work-related asthma among employees within an indoor *Cannabis* grow operation. A better understanding of the occupational hazards and health risks is urgently needed, particularly given the rapid expansion of *Cannabis* cultivation. In the interim, risk management strategies that encompass the hierarchy of controls should be developed and adopted. These should focus on engineering, administrative and PPE controls targeted at reducing *Cannabis* dust exposure, and other potential health hazards, within these facilities. Where respiratory protection is used to reduce employees exposure to *Cannabis* dust, employers should implement a comprehensive respiratory protection program, including provision of appropriate PPE is supplies, fit testing of workers, and appropriate training in respirator use.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

Funding

This work was supported by the award numbers 5 T42 OH008433 and U54 OH007544 from the National Institute of Occupational Safety and Health and by the National Institute of Environmental Health Sciences (P30ES007033). The content is solely the responsibility of the authors and does not necessarily represent the official views of the Centers for Disease Control or the National Institutes of Health.

Acknowledgments

We would additionally like to thank the study subjects for their participation and cooperation, and management of the cannabis producer for providing access to their worksite and employees.

Conflict of interest

The authors declare no conflict of interest.

References

American Thoracic Society; European Respiratory Society. (2005) ATS/ERS recommendations for standardized procedures for the online and offline measurement of exhaled lower respiratory nitric oxide and nasal nitric oxide, 2005. *Am J Respir Crit Care Med*; **171**: 912–30.

Burney PG, Luczynska C, Chinn S *et al.* (1994) The European Community Respiratory Health Survey. *Eur Respir J*; **7**: 954–60.

Butsic V, Brenner JC. (2016). *Cannabis* (*Cannabis sativa* or *C. indica*) agriculture and the environment: a systematic and spatially-explici survey and potential impact. *Environ Res Lett*; **11**: 044023.

Couch JR, Grimes GR, Wiegand DM *et al.* (2019) Potential occupational and respiratory hazards in a Minnesota cannabis cultivation and processing facility. *Am J Ind Med*; **62**: 874–82.

Cox J. (2019). The marijuana industry looks like the fastest-growing job market in the country. Available at, CNBC website, https://www.cnbc.com/2019/03/14/the-marijuana-industry-looks-like-the-fastest-growing-job-market-in-the-country.html. Accessed 5 September 2019.

Davidson M, Reed S, Oosthuizen J *et al.* (2018) Occupational health and safety in cannabis production: an Australian perspective. *Int J Occup Environ Health*; **24**: 75–85.

Decuyper II, Faber MA, Lapeere H *et al.* (2018) Cannabis allergy: a diagnostic challenge. *Allergy*; **73**: 1911–4.

Decuyper II, Rihs H-P, Van Gasse AL, *et al.* (2019a). Cannabis allergy: what the clinician needs to know in 2019. *Expert Rev Clin Immunol*; **15**: 599–606.

Decuyper I, Ryckebosch H, Van Gasse AL *et al.* (2015) Cannabis allergy: what do we know anno 2015. *Arch Immunol Ther Exp (Warsz)*; **63**: 327–32.

Decuyper II, Van Gasse AL, Cop N *et al.* (2017) *Cannabis sativa* allergy: looking through the fog. *Allergy*; **72**: 201–6.

Decuyper II, Van Gasse A, Faber MA, *et al.* (2019b). Occupational cannabis exposure and allergy risks. *Occup Environ Med*; **76**: 78–82.

Donham KJ, Thelin A. (2016). Agricultural respiratory diseases. In *Agricultural medicine*. Iowa: Wiley-Blackwell pp. 95–154

Dweik RA, Boggs PB, Erzurum SC *et al.*; American Thoracic Society Committee on Interpretation of Exhaled Nitric Oxide Levels (FENO) for Clinical Applications. (2011) An official ATS clinical practice guideline: interpretation of exhaled nitric oxide levels (FENO) for clinical applications. *Am J Respir Crit Care Med*; **184**: 602–15.

Er M, Emri SA, Demir AU *et al.* (2016) Byssinosis and COPD rates among factory workers manufacturing hemp and jute. *Int J Occup Med Environ Health*; **29**: 55–68.

Giese MW, Lewis MA, Giese L *et al.* (2015) Development and validation of a reliable and robust method for the analysis of cannabinoids and terpenes in cannabis. *J AOAC Int*; **98**: 1503–22.

Hankinson JL, Odencrantz JR, Fedan KB. (1999). Spirometric reference values from a sample of the general U.S. population. *Am J Respir Crit Care Med*; **159**: 179–87.

Herzinger T, Schöpf P, Przybilla B *et al.* (2011) IgE-mediated hypersensitivity reactions to cannabis in laboratory personnel. *Int Arch Allergy Immunol*; **156**: 423–6.

Johnson LI, Miller JD. (2012). Consequences of large-scale production of marijuana in residential buildings. *Indoor Built Environ*; **21**: 595–600.

Malo JL, Vandenplas O. (2011) Definitions and classification of work-related asthma. *Immunol Allergy Clin North Am*; **31**: 645–62, v.

Marijuana Occupational Health and Safety Work Group. (2017). Guide to worker safety and health in the Marijuana Industry_FULL REPORT.pdf—Google Drive. Available at, Colorado Department of Public Health & Environment website, https://drive.google.com/file/d/0B0tmPQ67k3NVb1IydUQxSkZRS1U/view. Accessed 5 September 2019.

Martyny JW, Serrano KA, Schaeffer JW *et al.* (2013) Potential exposures associated with indoor marijuana growing operations. *J Occup Environ Hyg*; **10**: 622–39.

McNamee R. (2005) Regression modelling and other methods to control confounding. *Occup Environ Med*; **62**: 500–6, 472.

Miller MR, Hankinson J, Brusasco V *et al*.; ATS/ERS Task Force. (2005) Standardisation of spirometry. *Eur Respir J*; **26**: 319–38.

Pekkanen J, Sunyer J, Anto JM *et al*.; European Community Respiratory Health Study. (2005) Operational definitions of asthma in studies on its aetiology. *Eur Respir J*; **26**: 28–35.

Pellegrino R, Viegi G, Brusasco V *et al*. (2005) Interpretative strategies for lung function tests. *Eur Respir J*; **26**: 948–68.

Reeb-Whitaker CK, Bonauto DK. (2014) Respiratory disease associated with occupational inhalation to hop (*Humulus lupulus*) during harvest and processing. *Ann Allergy Asthma Immunol*; **113**: 534–8.

Silvers WS, Bernard T. (2017) Spectrum and prevalence of reactions to marijuana in a Colorado allergy practice. *Ann Allergy Asthma Immunol*; **119**: 570–1.

Silvey B. (2019). Characterization of occupational exposure to airborne contaminants in an indoor cannabis production facility. University of Washington. Available at https://digital.lib.washington.edu/researchworks/handle/1773/44207 Accessed 21 September 2019.

Steigerwald S, Cohen BE, Vali M *et al*. (2019). Differences in opinions about marijuana use and prevalence of use by state legalization status. *J Addict Med*.

Team RC. (2015). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Victory KR, Couch J, Lowe B *et al*. (2018) Notes from the field: occupational hazards associated with harvesting and processing Cannabis—Washington, 2015–2016. *MMWR Morb Mortal Wkly Rep*; **67**: 259–60.

Walters KM, Fisher GG, Tenney L. (2018) An overview of health and safety in the Colorado cannabis industry. *Am J Ind Med*; **61**: 451–61.

Washington State Liquor and Cannabis Board. (2019). Producer license descriptions and fees | Washington State Liquor and Cannabis Board. Available at https://lcb.wa.gov/mjlicense/producer_license_discriptions_fees. Accessed 5 September 2019.

Williams C, Thompstone J, Wilkinson M. (2008) Work-related contact urticaria to *Cannabis sativa*. *Contact Dermatitis*; **58**: 62–3.

Zuskin E, Kanceljak B, Pokrajac D *et al*. (1990) Respiratory symptoms and lung function in hemp workers. *Br J Ind Med*; **47**: 627–32.