Evaluation of exposures and respiratory health at a coffee roasting and packaging facility and attached retail café

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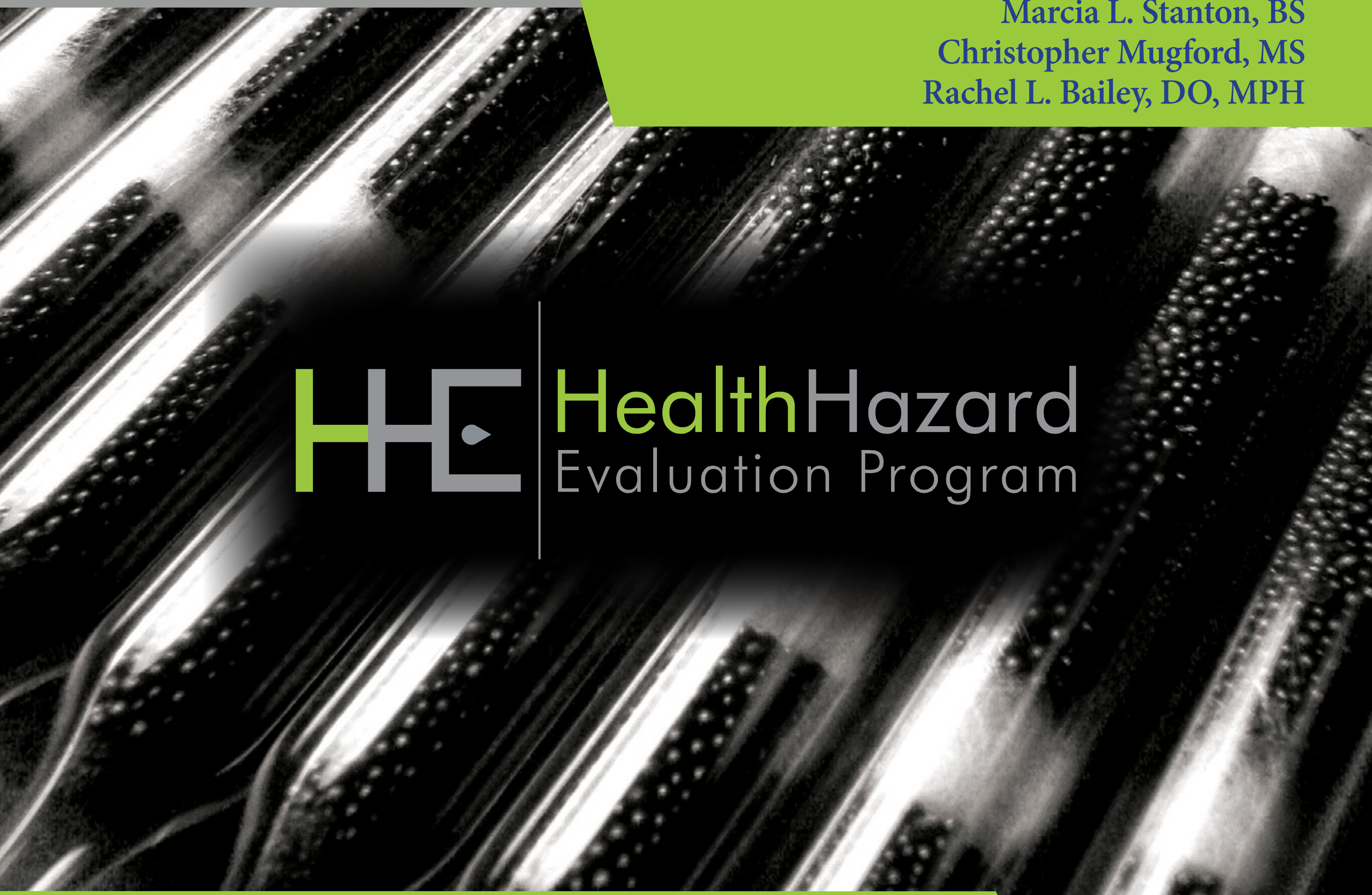

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Contents

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

Highlights of this Evaluation

The Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health received a request from the management at a coffee roasting and packaging facility and attached retail café regarding exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting and grinding.

What We Did

- We visited the coffee facility and attached retail café on March 4-5 and March 7-10, 2016.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione over multiple days during each visit.
- We collected roasted coffee beans (whole bean and ground) to measure their emission potential for diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We collected pre-and-post shift background air samples of diacetyl, 2,3-pentanedione, and 2,3-hexanedione to determine if air concentrations changed over the work day.
- We measured real-time air levels of carbon monoxide, carbon dioxide, and volatile organic compounds.
- We assessed the ventilation at the facility.
- We administered a health questionnaire to employees and performed breathing tests.

What We Found

- On full-shift sampling, two production employees and a roaster operator were exposed to diacetyl at concentrations slightly above the recommended exposure limit for diacetyl of 5 parts per billion, with the highest measured concentration of 5.9 parts per billion.

We evaluated respiratory health and potential exposures to alpha-diketones (diacetyl, 2,3-pentanedione, and 2,3-hexanedione), other volatile organic compounds, carbon monoxide, and carbon dioxide among employees at a coffee roasting and packaging facility and attached retail cafe. Three employees in the production area of the facility had full-shift exposures that exceeded the NIOSH recommended exposure limit for diacetyl. Nose and eye symptoms were the most commonly reported symptoms. Wheezing was the most commonly reported lower respiratory symptom; 1.7 times as many employees as expected reported this symptom than in the U.S. population with a similar demographic distribution. One participant had severe airways obstruction that improved after bronchodilator. One participant had high exhaled nitric oxide, a marker of allergic airways inflammation. We recommend ventilation changes; implementing administrative controls such as modification of work practices; and training employees about work-place hazards. We also recommend instituting a medical monitoring program.

- Levels of diacetyl and 2,3-pentanedione in the air during task-based sampling were highest for tasks involving grinding roasted beans (maximum: 65.9 parts per billion diacetyl and 39.6 parts per billion 2,3-pentanedione; duration of sample was 3 minutes) and scooping roasted beans from storage bins (maximum: 151 parts per billion diacetyl and 182 parts per billion 2,3-pentanedione; duration of the sample was approximately 30 seconds).
- Diacetyl and 2,3-pentanedione concentrations in the background samples increased slightly throughout the day on two of the three days sampled.
- The highest level of total volatile organic compounds measured was 4,390 parts per billion beside the sample roaster, followed by a peak of 1,317 parts per billion in the café between the espresso grinders.
- Carbon dioxide and carbon monoxide were highest near the roaster machine.
- All tested roasted coffee beans emitted diacetyl and 2,3-pentanedione.
- The three air-handling units appeared to be functional and well-maintained; however, the ventilation filters had an excessive amount of visible dust on them and needed to be replaced.
- Nose and eye symptoms were the most commonly reported symptoms. Some employees reported their symptoms were caused or aggravated by dust.
- Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom; 1.7 times as many employees reported wheezing than expected.
- One of 16 participants had severe airways obstruction that improved after bronchodilator.
- One participant had high exhaled nitric oxide, a marker of allergic airways inflammation.

What the Employer Can Do

- Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, carbon monoxide, carbon dioxide, green and roasted coffee dust) in the workplace and how to protect themselves.
- Change air-handler unit filters more frequently (such as monthly or quarterly) to maintain efficiency and proper airflow.
- Work with a qualified ventilation engineer to increase the amount of fresh, outdoor air supplied to the production space, to reduce air concentrations of alpha-diketones.
- If increasing general ventilation is not possible, install local exhaust ventilation to capture and remove airborne alpha-diketones during grinding and scooping of roasted coffee.
- Whenever feasible, use an alternative method to hand-blending for blending roasted coffee beans.

- Conduct follow-up sampling to verify that the modifications have been effective in reducing alpha-diketone exposures to below the recommended exposure limits.
- Make N95 disposable filtering facepiece respirators available for voluntary use for protection against dust exposure, such as when emptying burlap bags of green beans into the storage silos, cleaning the roaster exhaust system of chaff, emptying the chaff containers, or cleaning the green bean storage area.
- Encourage employees to report new, ongoing, or worsening respiratory symptoms to their personal healthcare providers and to a designated individual at the workplace.
- Institute a medical monitoring program for employees who work in the production area.

What Employees Can Do

- Avoid placing your head directly inside roasted bean storage bins.
- Follow your employer's instructions for an alternative method to hand-blending roasted coffee beans.
- Use controls such as local exhaust ventilation as instructed by your employer.
- Some employees may wish to use N95 disposable filtering facepiece respirators for some tasks, such as when emptying burlap bags of green beans into the storage silos, when cleaning the roaster exhaust system of chaff, when emptying the chaff containers, or when cleaning the green bean storage area.
- Report new, ongoing, or worsening respiratory symptoms to your personal healthcare provider(s) and a designated individual at your workplace.
- Participate in any personal air sampling offered by your employer.
- Participate in the medical monitoring program as instructed by your employer.

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Abbreviations

µm	Micrometer
µg	Microgram
°F	degrees Fahrenheit
ACGIH®	American Conference of Governmental Industrial Hygienists
AHU	Air-handling unit
APF	Assigned protection factor
AX	Area of reactance
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
FEV_1	1-second forced expiratory volume
Fres	Resonant frequency
FVC	Forced vital capacity
HVAC	Heating, ventilation, and air-conditioning
Hz	Hertz
kPa/(L/s)	Kilopascals per liter per second
IDLH	Immediately dangerous to life or health
LPM	Liters per minute
LOD	Limit of detection
LOQ	Limit of quantitation
mL	Milliliter
mL/min	Milliliter per minute
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppb	Parts per billion
ppm	Parts per million
QC	Quality control
R5	Resistance at 5 Hertz
R20	Resistance at 20 Hertz
REL	Recommended exposure limit

RH	Relative humidity
SMR	Standardized morbidity ratios
STEL	Short-term exposure limit
TLV®	Threshold limit value
TVOC	Total volatile organic compound
TWA	Time-weighted average
US	United States
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

In October 2015, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health received a request from the management of a coffee roasting and packaging facility with an attached café regarding concerns about exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting and grinding. In March 2016, we conducted an industrial hygiene survey, ventilation assessment, and medical survey at the facility. The industrial hygiene survey consisted of collecting personal breathing zone and area air samples for alpha-diketones (diacetyl, 2,3-pentanedione, and 2,3-hexanedione). Bulk samples of whole bean and ground roasted coffee were collected to evaluate the potential for emission of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We used continuous monitoring instruments to measure total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. We also conducted a ventilation assessment in the production, café, and office areas. The medical survey consisted of a health questionnaire and breathing tests.

Three of 20 personal full-shift samples exceeded the National Institute for Occupational Safety and Health recommended exposure limit for diacetyl of 5 parts per billion in the production area including a roaster operator (5.8 parts per billion), one production employee (5.9 parts per billion), and the production manager (5.1 parts per billion). Full-shift air concentrations of diacetyl were below this exposure limit for personal and area air samples collected in office areas and the attached retail café. Full-shift air concentrations of 2,3-pentanedione were below the National Institute for Occupational Safety and Health recommended exposure limit of 9.3 parts per billion for both personal and area air samples collected in the production area, office areas, and attached retail café. Through task-based sampling, we identified specific work tasks that resulted in elevated diacetyl and 2,3-pentanedione air concentrations. Specifically, grinding roasted coffee beans resulted in two separate peak exposures to diacetyl (maximum 65.9 parts per billion) and 2,3-pentanedione (maximum 39.6 parts billion). Scooping roasted beans by hand from a roasted bean storage bin also had elevated peak exposures with maximum exposures of 151 parts per billion diacetyl and 182 parts per billion 2,3-pentanedione.

Nose and eye symptoms were the most commonly reported symptoms. Wheezing was the most commonly reported lower respiratory symptom; 1.7 times as many employees as expected reported this symptom than in the U.S. population with a similar demographic distribution. One participant had severe airways obstruction and possible small airways abnormality on oscillometry, both improved after bronchodilator. Four other participants had abnormalities on oscillomtery but normal spirometry. One participant had high exhaled nitric oxide, a marker of allergic airways inflammation. We recommend increasing dilution ventilation and/or installing local exhaust ventilation. We also recommend administrative controls such as modification of work practices, training employees about work-place hazards, and instituting a medical monitoring program to identify any employees who may be developing work-related lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease.

Introduction

In October 2015, the National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation at a coffee roasting and packaging facility with an attached café. The request expressed concerns about exposures to diacetyl and 2,3-pentanedione during the coffee roasting and grinding process. In March 2016, we conducted an industrial hygiene survey, ventilation assessment, and medical survey. We collected area and personal breathing zone air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We sampled air concentrations of carbon monoxide (CO), carbon dioxide (CO_2), and total VOCs (TVOCs) using real-time continuous monitors. In March 2016, we provided an interim letter detailing our evaluations and preliminary recommendations.

Background

Diacetyl and 2,3-Pentanedione

Diacetyl (2,3-butanedione) and 2,3-pentanedione (acetyl propionyl) are VOCs known as alpha-diketones that are added as ingredients in food flavorings used in some food products such as microwave popcorn, bakery mixes, and flavored coffee [Day et al. 2011; Kanwal et al. 2006; Bailey et al. 2015]. Diacetyl, 2,3-pentanedione, other VOCs, and gases such as CO and CO_2 are naturally produced and released during the coffee roasting process [Duling et al. 2016; Raffel and Thompson 2013; Daglia et al. 2007; Nishimura et al. 2003; Newton 2002]. Grinding roasted coffee beans produces a greater surface area for off-gassing (sometimes called degassing) of these compounds [Akiyama et al. 2003]. Often, coffee roasting facilities package newly roasted coffee in permeable bags or in bags fitted with one-way valves to allow the coffee to off-gas after it is packaged. Sometimes, newly roasted coffee is placed in bins or containers and allowed to off-gas before packaging.

NIOSH has recommended exposure limits (RELs) for diacetyl and 2,3-pentanedione in workplace air (Table 1) [NIOSH 2016]. The NIOSH objective in establishing RELs for diacetyl and 2,3-pentanedione is to reduce the risk of respiratory impairment (decreased lung function) and the severe irreversible lung disease obliterative bronchiolitis associated with occupational exposure to these chemicals. NIOSH RELs are intended to protect workers exposed to diacetyl or 2,3-pentanedione for a 45-year working lifetime. The REL for diacetyl is based on a quantitative risk assessment which necessarily contains assumptions and some uncertainty. Analytical limitations current at the time were taken into consideration in setting the REL for 2,3-pentanedione. The RELs should be used as a guideline to indicate when steps should be taken to reduce exposures in the workplace.

These exposure limits and the accompanying recommendations for control of exposures were derived from a risk assessment of flavoring-exposed workers. At an exposure equal to the diacetyl REL, the risk of adverse health effects is low. NIOSH estimated that less than 1 in 1,000 workers exposed to diacetyl levels of 5 parts per billion (ppb) as a time-weighted average (TWA) for 8 hours a day, 40 hours a week for a 45-year working lifetime would develop reduced lung function (defined as forced expiratory volume in one second [FEV_1] below the 5^{th} percentile) as a result of that exposure. NIOSH predicted that around

1 in 10,000 workers exposed to diacetyl at 5 ppb for a 45-year working lifetime would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as at least moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). Workers exposed for less time would be at lower risk for adverse lung effects.

2,3-Hexanedione

2,3-Hexanedione is also an alpha-diketone that is sometimes used as a substitute for diacetyl and is produced naturally during coffee roasting. In a study using animals, there was some evidence that 2,3-hexanedione might also damage the lungs, but it appeared to be less toxic than diacetyl and 2,3-pentanedione [Morgan et al. 2016]. There are no established occupational exposure limits for 2,3-hexanedione.

Carbon Monoxide and Carbon Dioxide

CO and CO_2 are gases produced by combustion. They are also produced as a result of reactions that take place during coffee roasting. These gases are released during and after roasting and grinding, a process called off-gassing [Anderson et al. 2003]. High exposures to CO and CO_2 can cause headache, dizziness, fatigue, nausea, confusion, rapid breathing, impaired consciousness, coma, and death [Newton 2002; Nishimura et al. 2003; Langford 2005; CDC 2013a; Raffel and Thompson 2013; Rose et al. 2017]. Occupational exposure limits for CO and CO_2 are listed in Table 1.

Obliterative Bronchiolitis

Obliterative bronchiolitis is a serious, often disabling, lung disease that involves scarring of the very small airways (i.e., bronchioles). Symptoms of this disease may include cough, shortness of breath on exertion, and/or wheeze, that do not typically improve away from work [NIOSH 2012]. Occupational obliterative bronchiolitis has been identified in flavoring manufacturing workers and microwave popcorn workers who worked with flavoring chemicals or butter flavorings [Kreiss 2013; Kim et al. 2010; Kanwal et al. 2006]. It has also been identified in employees at a coffee processing facility that produced unflavored and flavored coffee [CDC 2013b]. A NIOSH health hazard evaluation at that facility found diacetyl and 2,3-pentanedione concentrations in the air that were concerning and identified three sources: 1) flavoring chemicals added to roasted coffee beans in the flavoring area; 2) grinding unflavored roasted coffee beans and packaging unflavored ground and whole bean roasted coffee in a distinct area of the facility, and 3) storing roasted coffee in hoppers, on a mezzanine above the grinding/packaging process, to off-gas [Duling et al. 2016]. At the time of the health hazard evaluation, workers had excess shortness of breath and obstruction on spirometry, both consistent with undiagnosed lung disease. Respiratory illness was associated with exposure and not limited to the flavoring areas [Bailey et al. 2015]. However, all workers who were diagnosed with obliterative bronchiolitis had worked in the flavoring area. To date, no cases of obliterative bronchiolitis have been reported in workers at coffee processing facilities that produce only unflavored coffee.

Work-related Asthma

Work-related asthma refers to asthma that is brought on by ("occupational asthma") or made worse by ("work-exacerbated asthma" or "work-aggravated asthma") workplace exposures

[Tarlo 2016; Tarlo and Lemiere 2014; OSHA 2014; Henneberger et al. 2011]. It includes asthma due to sensitizers, which cause disease through immune (allergic) mechanisms, and asthma due to irritants, which cause disease through non-immune mechanisms. Symptoms of work-related asthma include episodic shortness of breath, cough, wheeze, and chest tightness. The symptoms may begin early in a work shift, towards the end of a shift, or hours after a shift. They generally, but do not always, improve or remit during periods away from work, such as on weekends or holidays.

Green and roasted coffee dust and castor beans (from cross-contamination of bags used to transport coffee) are known risk factors for occupational asthma [Figley and Rawling 1950; Karr et al. 1978; Zuskin et al. 1979, 1985; Thomas et al. 1991]. Persons who become sensitized (develop an immune reaction) to coffee dust can subsequently react to relatively low concentrations in the air. Others may experience irritant-type symptoms from exposure to coffee dust [Oldenburg et al. 2009].

Process Description

Established in 1999, the company opened the retail café and coffee processing facility in the current location in 2013. The facility included a production area, office space, and an attached retail café. There was a basement that was used mainly for storage of equipment, supplies, and green beans. The production area was approximately 4,300 square feet. The café area was approximately 8,000 square feet. There were 24 employees at the time of the survey. Six employees were involved in production tasks including, but not limited to, roasting, weighing and packaging, grinding, and quality control. Eleven employees worked in the café. The seven remaining employees were involved in various administrative tasks including graphic design, sales, and marketing; three assisted in the café sometimes. The following process description describes activities at the time of the NIOSH visit in March 2016.

Coffee Processing

Green beans were received in burlap bags from around the world including, but not limited to, Columbia, Guatemala, Mexico, Brazil and Peru. Upon arrival at the facility, burlap bags of green beans were stored on wooden pallets in the green bean receiving area in the basement. To prepare a batch for roasting, a roaster operator scooped green beans directly from the burlap bags into a hopper equipped with a scale, located on the floor. The roasting machine was a Loring Kestrel S35 Roaster; typical roasts were 50 pounds. Green beans were automatically conveyed from the hopper into the roasting drum where they were heated at a specific temperature for a given time period depending on the desired roast. Time and temperature varied between different types of roasts. At the end of each roasting cycle, a door at the bottom of the roasting drum automatically opened to dispense the roasted beans into a cooling drum where they were automatically mixed by an agitator to accelerate cooling. The cooling drum utilized a downdraft exhaust system that drew air over the roasted beans and down into the cooling drum to accelerate cooling. The downdraft system exhausted through the roof. After cooling, the roasted beans were emptied from the cooling drum into plastic storage containers. A roaster operator then manually moved the containers to the roasted bean storage area and covered with a lid.

There were two main ways to prepare roasted beans for packaging. The roasted beans were packaged as single origin coffee or blends that were prepared by combining beans from several origins. Blends were prepared by one of two methods depending on the size of the order. Smaller blends were made by manually mixing various roasted coffees in a plastic container. For larger blends, the cooling drum of a roaster was used where the beans were automatically mixed by an agitator. For individual orders (such as online orders), an employee manually scooped roasted beans from the plastic storage container onto a scale to obtain the desired weight for the order. The roasted beans were then manually transferred into their respective package and heat sealed. The package was placed inside a cardboard box and labeled for delivery or shipment. For larger orders with multiple packages, the employee transferred the desired type of roasted beans into the hopper of an automatic auto-fill machine. The auto-fill machine dispensed the roasted beans into packages by weight. One and five pound packages were mainly used. The packages were either placed in a cardboard box and labeled for delivery or shipment, or stored on shelves until needed.

For ground coffee, an employee manually scooped roasted beans from their respective plastic storage containers onto a scale to obtain the desired weight for the order. The employee then transferred the roasted beans into the grinder hopper. The empty package was placed at the bottom of the grinder and collected the ground coffee. There were two identical grinding machines. The grinders could be adjusted for type of grind (coarse, light-medium, or fine). After the packages were filled with ground coffee, they were heat sealed and packaged for delivery, shipment, or stored on shelves until needed.

Quality Control

The company took measures to ensure quality of green and roasted beans. The facility had a quality control room located in the café where roasted beans and brews could be prepared and assessed. The company also offered training to other companies that brewed their coffee and used their coffee equipment. There was also a sample roaster in the production area to profile incoming green beans to determine the best roast (roast temperature and time). Within each specific type of roast, the roasted beans were packaged in the order they were roasted to ensure freshness.

Cleaning Activities

Cleaning methods used for the production area and equipment included sweeping and vacuuming. Employees used brooms to sweep the production floor and vacuums to clean equipment. The chaff drum of the roaster was emptied at the end of each day. The roaster was cleaned by vacuuming out the different compartments of the machine where chaff accumulated. The facility had a wash station in the production area to wash buckets and containers for reuse.

Personal Protective Equipment

Employees were not required to wear a company uniform or protective clothing. We did not observe employees wearing any respiratory protection for chemicals or dust at the time of our visit. Hearing protection was available for voluntary use. We noted one employee wearing hearing production during roasting tasks.

Retail Café and Office Areas
The front portion of the facility was dedicated to the café, quality control area, and offices. The café was approximately 8,000 square feet and had a posted maximum seating of 222 patrons. The wall behind the serving area of the café was open to the production room. The café operated seven days a week and also served food that was prepared elsewhere and delivered. The serving area of the café was equipped with three coffee grinders, one espresso machine with three brew elements and two steam elements, and a one-gallon twin coffee brewer system. For some specialty coffee drinks, liquid flavored syrups were added to the roasted coffee drinks when requested by customers. Four administrative offices were adjacent to the café.

Methods

We visited the coffee processing facility and café in March 2016. We performed the industrial hygiene survey on March 4-5 and March 7-8, 2016. On the morning of first day, we held an opening meeting with management and employees to describe the sampling. During the remainder of the time, we collected bulk samples of roasted coffee, collected air samples, and performed a ventilation assessment. We performed the medical survey on March 9-10, 2016. We provided an interim letter detailing our evaluations and preliminary recommendations on April 6, 2016.

The objectives for this evaluation were the following:

1. Measure employees exposure to diacetyl, 2,3-pentanedione, and 2,3-hexanedione during coffee processing and café activities;
2. Identify process areas or work tasks associated with emissions of diacetyl, 2,3-pentanedione, and 2,3-hexanedione;
3. Measure levels of CO and CO_2 throughout the facility;
4. Measure pre- and post-shift air concentrations of diacetyl, 2,3-pentanedione, and 2,3-hexanedione to determine if concentrations change over the work shift;
5. Assess ventilation systems and their effect on exposure levels;
6. Determine if employees had mucous membrane, respiratory, or systemic symptoms and the proportion of those symptoms that were work-related or aggravated by work;
7. Determine if employees had abnormal lung function tests, and
8. Compare employees' prevalence of lower respiratory symptoms and healthcare provider-diagnosed asthma to expected levels based on general population values.

Industrial Hygiene Survey
Sampling Times for Alpha-Diketones
We designed the sampling strategy to assess full-shift exposures and to identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. For diacetyl, 2,3-pentanedione, and 2,3-hexanedione, air samples were collected over seconds,

minutes, and hours. Samples collected over hours can help determine average concentrations that can be compared to the NIOSH RELs for diacetyl and 2,3-pentanedione. These average concentrations do not tell us about short-term peak exposures that could be relevant to respiratory health, particularly when tasks are repeated multiple times per day. Therefore, during particular tasks, we collected air samples over several minutes. We also conducted instantaneous sampling over seconds to help identify point sources of alpha-diketones.

Air Sampling and Analysis Using Occupational Safety and Health Administration (OSHA) Methods 1013/1016

We collected personal and area air samples for diacetyl, 2,3-pentanedione, and 2,3-hexanedione on silica gel sorbent tubes. The samples were collected and analyzed according to the modified OSHA sampling and analytical Methods 1013/1016 [OSHA 2008; OSHA 2010; LeBouf and Simmons 2017]. In accordance with the two methods, two glass silica gel sorbent tubes were connected by a piece of tubing and inserted into a protective, light-blocking cover. The tubes were connected in series to a sampling pump pulling air through the tubes at a flow rate of 50 milliliters per minute (mL/min). The sampling setup was attached to an employee's breathing zone or placed in an area basket in various places throughout the facility. For full-shift sampling, we collected two consecutive 3-hour samples and calculated the TWA concentration from the two samples, assuming that the total 6-hour monitoring results reflected a full work shift (8-hour) TWA exposure. We refer to these samples as "full-shift samples" throughout this report. We also collected short-term task-based samples in the same manner, but the sampling pump flow rate was 200 mL/min as detailed in OSHA Methods 1013 and 1016 [OSHA 2008, 2010]. Sampling times were dependent on the duration of the task being performed.

Analyses of the samples were performed in the NIOSH Respiratory Health Division's Organics Laboratory. The samples were extracted for one hour in 95% ethanol:5% water containing 3-pentanone as an internal standard. Samples were analyzed using an Agilent 7890/7001 gas chromatograph/mass spectrometer system operated in selected ion monitoring mode for increased sensitivity compared to the traditional flame ionization detector used in OSHA Methods 1013 and 1016 [LeBouf and Simmons 2017].

A limit of detection (LOD) is the lowest mass that an instrument can detect above background and is a criteria used to determine whether to report a result from a sample. The LODs were 0.01 micrograms per sample (µg/sample) for diacetyl, 0.012 µg/sample for 2,3-pentanedione, and 0.020 µg/sample for 2,3-hexanedione. These equate to 0.32 ppb for diacetyl, 0.33 ppb for 2,3-pentanedione, and 0.48 ppb for 2,3-hexanedione for a typical full-shift air sample but will vary depending on the volume of sample collected. The LODs for task samples are generally higher than typical LOD values for full-shift samples since the air volumes collected during task samples are lower. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol. The limit of quantitation (LOQ) is the lowest mass that can be reported with precision; we have a greater confidence in the reported result if it is above the LOQ. The LOQs equate to 1.1 ppb for diacetyl, 1.1 ppb for 2,3-pentanedione, and 1.6 ppb for 2,3-hexanedione for a typical full-shift air sample.

Air Sampling and Analysis Using Evacuated Canisters

We collected instantaneous task-based and source air samples for VOCs including diacetyl, 2,3-pentanedione, and 2,3-hexanedione using evacuated canisters. We also collected instantaneous air samples before and after the work shift to determine if air concentrations of alpha-diketones increased over a work shift. The evacuated canister sampling setup consisted of a 450-mL evacuated canister equipped with an instantaneous flow controller that was designed for a short sampling duration (less than 30 seconds). Instantaneous samples were taken by opening the evacuated canister to grab a sample of air to help identify point sources of alpha-diketones. For task-based air samples, a NIOSH employee placed the inlet of the flow controller by the employee's personal breathing zone as they performed their work task to replicate exposure. For source air samples, a NIOSH employee placed the inlet of the flow controller directly at the source of interest.

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system pursuant to a published method validation study [LeBouf et al. 2012], with the following modifications: the pre-concentrator was a Model 7200 (Entech Instruments, Inc., Simi Valley, CA), and six additional compounds, diacetyl, 2,3-pentanedione, 2,3-hexanedione, acetaldehyde, acetonitrile, and styrene, were included. At present, this canister method is partially validated [LeBouf et al. 2012] and not considered the standard method. The LODs were 0.39 ppb for diacetyl, 0.74 ppb for 2,3-pentanedione, and 1.2 ppb for 2,3-hexanedione based on a 1.5-times dilution factor, which is typical for instantaneous samples. However, LODs are dependent on the pressure inside each canister after the samples have been collected, and they may be higher or lower than typical LOD values.

Bulk Sampling and Headspace Analysis

We used 50-mL sterile polypropylene centrifuge tubes to collect approximately 40-mL bulk samples of whole roasted coffee beans. For headspace analysis of alpha-diketones, we transferred one gram of solid bulk material into a sealed 40-mL amber volatile organic analysis vial and let it rest for 24 hours at room temperature (70°F) in the laboratory. Then 2 mL of headspace air was transferred to a 450-mL canister and pressurized to approximately 1.5 times atmospheric pressure. Using the canister analysis system, the concentrations were calculated in ppb of analytes in the headspace as an indicator of emission potential.

Real-time Air Sampling

We used RAE Systems (San Jose, CA) ppbRAE 3000 (Model #PGM-7340) monitors to measure concentrations of TVOCs in the air. The ppbRAE has a non-specific photoionization detector that responds to chemicals with ionization potentials below the energy of the lamp. This sampling was conducted to identify areas where coffee could be releasing TVOCs. Areas where higher concentrations of TVOCs are measured may benefit from further sampling to characterize specific exposures to alpha-diketones. We also collected real-time measurements of CO_2, CO, temperature, and relative humidity (RH) using TSI Incorporated (Shoreview, MN) VelociCalc Model 9555-X Multi-Function Ventilation Meters equipped with Model 982 IAQ probes.

Exposure Limits
We utilize mandatory (legally enforceable) and recommended occupational exposure limits (OELs) when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures.

Occupational Safety and Health Administration (OSHA)
The U.S. Department of Labor's OSHA permissible exposure limits (PELs) are legal limits that are enforceable in workplaces covered under the Occupational Safety and Health Act. OSHA PELs represent the legal maximum for a TWA exposure to a physical or chemical agent over a work shift [OSHA 2017]. OSHA STELs are the legal maximum average exposure for a 15-minute time period. Some chemicals also have an OSHA ceiling value which represent levels that must not be exceeded at any time. Currently, there are no PELs for diacetyl, 2,3-pentanedione, or 2,3-hexanedione. For substances for which an OSHA PEL has not been issued, violation of the OSHA General Duty Clause can be considered using available occupational exposure references and recommendations [OSHA 1993; OSHA 2003], such as the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs®) and NIOSH RELs.

American Conference of Governmental Industrial Hygienists (ACGIH)
ACGIH is a professional, not-for-profit scientific association that reviews existing published, peer-reviewed scientific literature and publishes recommendations for levels of substances in air based on an 8-hour workday and 40-hour workweek. These recommendations are called TLVs [ACGIH 2017a]. ACGIH TLVs are not standards; they are health-based guidelines derived from scientific and toxicological information. ACGIH provides TLV-TWA guidelines that are levels that should not be exceeded during any 8-hour workday of a 40-hour workweek. ACGIH also provides TLV-STEL guidelines which are 15-minute exposure levels that should not be exceeded during a workday. Exposures above the TLV-TWA but less than the TLV-STEL should be (1) less than 15 minutes, (2) occur no more than four times a day, and (3) be at least 60 minutes between exposures [ACGIH 2017a]. Additionally, ACGIH provides TLV-Ceiling values which are levels that should not be exceeded at any time during a work shift. The ACGIH TLV-TWA for diacetyl is 10 ppb. The TLV-STEL for diacetyl is 20 ppb. Currently, there is no TLV-TWA or TLV-STEL for 2,3-pentanedione. ACGIH has placed 2,3-pentanedione on the 2017 list of Chemical Substances and Other Issues Under Study [ACGIH 2017b].

National Institute for Occupational Safety and Health (NIOSH)
NIOSH provides RELs as TWA concentrations that should not be exceeded over an 8 or 10-hour work shift, during a 40-hour workweek [NIOSH 2010]. RELs are intended to be protective over a 45-year working lifetime. NIOSH also provides STELs which are 15-minute TWA exposures that should not be exceeded at any time during a workday [NIOSH 2010]. Some chemicals have ceiling values which are concentrations that should not be exceeded at any time [NIOSH 2010]. For some chemicals, NIOSH has established an Immediately Dangerous to Life or Health (IDLH) value. An IDLH value is a concentration of an air contaminant that can cause death or immediate or delayed permanent adverse

health effects, or prevent escape from such an environment. Currently, NIOSH has RELs and STELs for diacetyl and 2,3-pentanedione. NIOSH does not have a REL or a STEL for 2,3-hexanedione. NIOSH does not have ceiling limits or IDLH values for diacetyl, 2,3-pentanedione, or 2,3-hexanedione.

For diacetyl and 2,3-pentanedione, the NIOSH RELs are 5.0 ppb and 9.3 ppb, respectively, as a TWA for up to an 8-hour workday during a 40-hour workweek (Table 1). The NIOSH STELs are 25 ppb for diacetyl and 31 ppb for 2,3-pentanedione [NIOSH 2016]. The NIOSH exposure limits do not differentiate between natural and synthetic chemical origin of diacetyl or 2,3-pentanedione. Although the NIOSH exposure limit for 2,3-pentanedione is above that of diacetyl, 2,3-pentanedione has been shown to be as hazardous as diacetyl [Hubbs et al. 2012; Morgan et al. 2012]. The hazard potential probably increases when these chemicals occur in combination with each other; having exposure to chemicals with the same functional alpha-diketone group and effect on the same system or organ (e.g., lungs) can result in additive effects [ACGIH 2017a]. The NIOSH REL is higher for 2,3-pentanedione than for diacetyl largely because analytic measures were not available in a validated OSHA method to detect 2,3-pentanedione at lower levels. In addition to the REL, NIOSH also recommends an action level for diacetyl of 2.6 ppb to be used with exposure monitoring in an effort to ensure employee exposures are routinely below the diacetyl REL. When exposures exceed the action level, employers should take corrective action (i.e., determine the source of exposure, identify methods for controlling exposure) to ensure that exposures are maintained below the NIOSH REL for diacetyl [NIOSH 2016].

Table 1. Personal exposure limits for compounds sampled for during the NIOSH survey, March 2016.

Compound	OSHA*	ACGIH		NIOSH		
	PEL	TLV	STEL	REL	STEL	IDLH
Diacetyl	-	10 ppb	20 ppb	5.0 ppb†	25 ppb	-
2,3-Pentanedione	-	-	-	9.3 ppb†	31 ppb	-
2,3-Hexanedione	-	-	-	-	-	-
Carbon dioxide	5,000 ppm	5,000 ppm	30,000 ppm	5,000 ppm	30,000 ppm	40,000 ppm
Carbon monoxide§	50 ppm	25 ppm	-	35 ppm	200 ppm (ceiling limit)¶	1,200 ppm

Note: OSHA=Occupational Safety and Health Administration; ACGIH=American Conference of Governmental Industrial Hygienist; NIOSH=National Institute for Occupational Safety and Health; PEL=permissible exposure limit; STEL=short-term exposure limit; TLV=threshold limit value; REL=recommended exposure limit; IDLH=immediately dangerous to life or health; ppb=parts per billion; ppm=parts per million; "-"=no exposure limit available.
***There are no OSHA STELs for the compounds in the table.**
†The NIOSH RELs for diacetyl and 2,3-pentanedione are time-weighted averages for up to an 8-hour day, during a 40-hour workweek.
§OSHA and NIOSH limits are designed for occupational exposure measurements in manufacturing and other trades that have potential sources of carbon dioxide or carbon monoxide (e.g., coffee roasting, welding, vehicle exhaust, diesel engine exhaust). Typical levels of carbon monoxide in offices are 0–5 ppm. In office settings, carbon dioxide generally should not be greater than 700 ppm above outdoor carbon dioxide levels; this typically corresponds to indoor concentrations below 1,200 ppm.
¶This is the NIOSH ceiling exposure limit for carbon monoxide. A ceiling concentration should not be exceeded at any time.

Ventilation Assessment
We collected physical measurements of all rooms and calculated approximate room volumes. Air flow measurements of supply vents and exhaust outlets were taken using an Accubalance Plus Model 8373 Air Capture Hood (TSI Incorporated, Shoreview, MN) or a TSI VelociCalc Plus Model 8324 Rotating Vane Anemometer, depending on which was most appropriate for the ventilation component being measured. The complete set of ventilation measurements allowed the calculation of volumetric flow rates in cubic feet per minute (cfm) into and out of each area.

Medical Survey
NIOSH Medical Survey
Participants
We invited all current employees to participate in the medical survey at the workplace on March 9-10, 2016. Participation was voluntary; written informed consent was obtained from each participant before testing. The survey included, in the order performed, a medical and work history questionnaire, quantification of exhaled nitric oxide, impulse oscillometry, spirometry, and if indicated the administration of a bronchodilator with repeat impulse oscillometry and spirometry. We mailed participants their individual reports explaining their breathing test results and recommended each participant provide the information to their personal physician.

Questionnaire
We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee facility and other coffee or flavoring companies, and cigarette smoking history. Questions on respiratory health were derived from five standardized questionnaires, the European Community Respiratory Health Survey [Burney et al. 1994; ECRHS 2014], the American Thoracic Society adult respiratory questionnaire (ATS-DLD-78) [Ferris 1978], the International Union Against Tuberculosis and Lung Disease [Burney and Chinn 1987; Burney et al. 1989], and the Third National Health and Nutrition Examination Survey (NHANES III) [CDC 1996] and NHANES 2007-2012 questionnaires [NCHS 2015]. Some of the questions appeared on more than one of the standardized questionnaires. We also supplemented our questionnaire with additional respiratory and systemic symptom questions.

Spirometry
The purpose of the spirometry test was to determine a person's ability to move air out of their lungs. Test results were compared to expected normal values. The test included three measurements or calculations: 1) forced vital capacity (FVC) (the total amount of air the participant can forcefully blow out after taking a deep breath), 2) FEV_1 (the amount of air that the participant can blow out in the first second of exhaling), and 3) the ratio of FEV_1 to FVC. We used American Thoracic Society criteria for acceptability and repeatability [Miller et al. 2005].

We used a volume spirometer (dry rolling seal spirometer) to measure exhaled air volume and flow rates. We used equations for predicted values and lower limits of normal derived from NHANES III data to define abnormal spirometry [Hankinson et al. 1999]. We defined obstruction as an FEV_1/FVC ratio less than the lower limit of normal with FEV_1 less than the lower limit of normal; restriction as a normal FEV_1/FVC ratio with FVC less than the lower limit of normal; and mixed obstruction and restriction as having FEV_1, FVC, and FEV_1/FVC ratio all less than the lower limit of normal. We used the FEV_1 percent predicted to categorize such abnormalities as mild, moderate, moderately severe, severe, or very severe [Pellegrino et al. 2005].

Impulse Oscillometry

Many occupational lung diseases (e.g., chronic obstructive pulmonary disease (COPD), asthma) involve the small airways; however, this part of the lung is difficult to evaluate non-invasively. Oscillometry is a helpful technology to understand the effects of occupational exposures on the small airways. There are no contraindications to the test as this test is conducted using regular breathing and does not require a forceful exhalation [Smith et al. 2005]. Spirometry can be normal despite respiratory symptoms or evidence of small airways disease on lung biopsy [King et al. 2011; Oppenheimer et al. 2007]; therefore, oscillometry results complement spirometry and can be used when spirometry is not possible because of a contraindication.

We used an impulse oscillometry machine (CareFusion Corp., San Diego, CA) to measure resistance (R), the energy required to propagate the pressure wave through the airways, and reactance (X), which reflects the viscoelastic properties of the respiratory system. The impulse oscillometry testing machine sends sound waves called pressure oscillations at different frequencies (e.g., 5 Hertz and 20 Hertz) into the airways to measure how airways respond to these small pressures. The test calculates 1) the airway resistance at different frequencies including 5 Hertz (R5) and 20 Hertz (R20), and the difference between R5 and R20 (DR5-R20); 2) the reactance at different frequencies including 5 Hertz (X5); 3) resonance frequency (Fres) which is the frequency where there is no airway reactance; and 4) the total reactance (AX) at all frequencies between 5 Hertz and the Fres. The predicted values for R and X were based on sex and age according to reference values recommended by the manufacturer [Vogel and Smidt 1994]. R5 was considered abnormal (elevated) if the measured value was equal to or greater than 140 percent of the predicted R5. X5 was considered abnormal (decreased) if the value of the predicted X5 minus measured X5 was equal to or greater than 0.15 kilopascals per liter per second (kPa/(L/s)). DR5-R20 values greater than 30% were considered abnormal and evidence of frequency dependence [Smith 2015]. We interpreted the test as normal if both the R5 and X5 were normal [Smith 2015]. We defined possible large (central) airways abnormality as a normal X5 and elevated R5 with no evidence of frequency dependence. We defined a possible small airways abnormality if there was evidence of frequency dependence and/or a decreased X5 with or without an elevated R5. We defined possible combined small (peripheral) and large (central airways) abnormality as a decreased X5 and elevated R5 with no evidence of frequency dependence.

Bronchodilator Reversibility Testing for Impulse Oscillometry and Spirometry

If a participant had abnormal impulse oscillometry or spirometry, we repeated both tests after the participant received a bronchodilator inhaler medication (i.e., albuterol), which can open the airways in some individuals (e.g., asthmatics). For oscillometry, we defined reversibility (improvement) after bronchodilator administration as a decrease of at least 20% of either Fres or R5 or a decrease of 40% for AX. For spirometry, we defined reversibility (improvement) as increases of at least 12% and 200 mL for either FEV_1 or FVC after bronchodilator administration.

Fractional Exhaled Nitric Oxide (FeNO)
We used the NIOX MINO® device (Aerocrine Inc., Morrisville, NC) to measure the amount of nitric oxide in the air the participant breathed out. Nitric oxide is a gas that is produced by the airways, and elevated levels can be a sign of eosinophilic airway inflammation in asthma [Dweik et al. 2011]. In adults, fractional nitric oxide concentration in exhaled breath levels above 50 ppb are considered elevated. In adults with asthma, elevated levels may indicate that their asthma is uncontrolled [Dweik et al. 2011].

Statistical Analysis
Industrial Hygiene Survey and Ventilation Assessment
We performed analyses using Excel (Microsoft®, Redmond, WA) and SAS version 9.3 (SAS Institute, Cary, NC). We created summary statistics by work area location, job title, and task. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

Medical Survey
We calculated frequencies and standardized morbidity ratios (SMRs) and their associated 95% confidence intervals (CIs) using SAS version 9.3 (Cary, NC). The SMRs compared prevalences of symptoms and spirometric abnormalities among participants to expected prevalences of a sample of the general population reflected in the NHANES III (1988–1994, symptom and spirometry data), NHANES 2007–2012 (symptom data), and NHANES 2007–2010 (spirometry data) adjusting for sex, race/ethnicity, age (less than 40 years old or 40 years or greater), and cigarette smoking categories (ever/never). For comparisons to the U.S. population, we used the most recent NHANES survey available for the specific comparisons. The small number of participants limits the conclusions that can be drawn from these analyses. Nonetheless, we report these results to provide some context for how commonly these symptoms and diagnoses are reported by adults in the general population.

Results

Industrial Hygiene Survey Results

Personal and Area Full-shift Air Sampling Results
<u>OSHA Methods 1013/1016</u>
Table A1 presents the area and personal full-shift air sampling results by location. Thirteen employees participated in the personal sampling. We collected 20 personal (17 production, 3 café) and 36 area (27 production, 9 café) full-shift air samples.

Three (15%) of the 20 personal air samples exceeded the NIOSH REL for diacetyl of 5.0 ppb while all personal air samples were below the NIOSH REL for 2,3-pentanedione of 9.3 ppb. The three personal samples exceeding the diacetyl REL were from a roaster operator (5.8 ppb), one production employee (5.9 ppb) and the production manager (5.1 ppb). The roaster operator spent the morning roasting coffee and then spent the remainder of the time cleaning the roaster machine and doing other miscellaneous tasks. The production employee spent the majority of time packaging coffee but also spent time grinding coffee and doing cleaning activities. No information was collected on the amount of time the production manager spent in the production area. 2,3-Hexanedione concentrations were below the LOD in all of the personal full-shift samples.

Thirty-six area samples were collected in fourteen locations throughout the facility. Within the production area, samplers were positioned at seven locations: 1) the roaster; 2) packaging; 3) roasted coffee storage; 4) labeling; 5) heating, ventilating, and air-conditioning air intake; 6) the opening between the production space, and 7) the café. Diacetyl concentrations in the production area ranged from less than 0.3 ppb to 9.0 ppb, and 2,3-pentanedione concentrations ranged from less than 0.3 ppb to 6.4 ppb. The maximum concentration for diacetyl (9.0 ppb) and 2,3-pentanedione (6.4 ppb) were measured on day one (Friday) in the area sample located in the production area at packaging near a grinder. On day three (Monday) in the same location, the concentrations were 7.1 ppb diacetyl and 5.9 ppb 2,3-pentanedione. In the café (9 samples), diacetyl concentrations ranged from less than 0.3 ppb to 3.7 ppb, and 2,3-pentanedione concentrations ranged from less than 0.3 ppb to 3.7 ppb. 2,3-Hexanedione concentrations were below the LOD in all of the area full-shift samples.

Personal Task-Based Air Sampling Results

OSHA Method 1013/1016

We collected 43 personal task-based air samples using OSHA Method 1013/1016 (Table A2). Grinding roasted coffee beans resulted in the highest measured concentrations of diacetyl (65.9 ppb and 50.5 ppb) and 2,3-pentanedione (39.6 ppb and 32.7 ppb); the durations of these samples were 3 minutes and 5 minutes, respectively. A majority of task-based samples were collected for greater than 15 minutes; all these samples were below the NIOSH STELs for diacetyl and 2,3-pentanedione. All task sample results were below the LOD for 2,3-hexanedione (range: less than 1.0 ppb to less than 7.1 ppb).

Evacuated Canisters

We collected 16 personal task-based air samples for approximately 30 seconds using an instantaneous flow controller (Table A3). Tasks sampled in the café showed lower air concentrations for alpha-diketones than production area or quality control tasks of the same type (such as grinding). These differences may be attributable to smaller volumes of roasted coffee used in the café compared to the production area or different bean origins, roasts, and types of coffee ground during these tasks. In total, six production employees who scooped roasted beans by hand from a roasted bean storage bin had diacetyl concentrations ranging from 5.7 ppb – 151 ppb and 2,3-pentanedione concentrations ranging from 3.6 ppb – 182 ppb. A production employee who scooped roasted beans by hand from a roasted bean storage bin had the highest exposure to diacetyl (151 ppb) and 2,3-pentanedione (182 ppb). Another task that had considerable alpha-diketone concentrations was in quality control during the cupping of fresh espresso grinds (101 ppb diacetyl and 149 ppb 2,3-pentanedione). The maximum 2,3-hexanedione concentration of 7.5 ppb was observed in quality control during the cupping of fresh espresso grinds.

Source Evacuated Canister Air Sampling Results

We collected 24 source air samples using instantaneous evacuated canisters (Table A4). To collect the source samples the inlet of the flow controller was placed directly at the source of interest. Overall, grinding resulted in the highest concentrations of diacetyl (maximum: 652 ppb in production and 1,079 ppb in quality control), 2,3-pentanedione (maximum: 408 ppb in production and 855 ppb in quality control), and 2,3-hexanedione (maximum: 20.3 ppb in quality control) with the concentrations varying with the roasts, types, and weights of the coffee ground.

Background Pre- and Post-Shift Evacuated Canister Air Sampling Results

We collected instantaneous evacuated canisters before and after the work shift to assess background concentrations of alpha-diketones (Table A5). Alpha-diketone concentrations increased slightly throughout the day on two of the three days. For example, background air concentrations for day one (production area) increased by 1.7 ppb diacetyl (1.9 to 3.6 ppb) and 1.5 ppb 2,3-pentanedione (1.4 to 2.9 ppb) over the work shift. All 2,3-hexanedione measurements were less than 0.6 ppb to 0.8 ppb with no discernable trend between before or after shift measurements.

Bulk Samples and Headspace Results

We observed varying concentrations of bulk headspace alpha-diketone concentrations depending on coffee origin and roast type (light, light-medium, medium) (Table A6). All bulk samples were roasted whole bean. Headspace concentrations ranged from 189 ppb to 1,312 ppb for diacetyl and from 269 ppb to 1,655 ppb for 2,3-pentanedione. The highest headspace concentrations of diacetyl (1,312 ppb) and 2,3-pentanedione (1,655 ppb) were in roasted beans from Rwanda. All 2,3-hexanedione measurements were below the LOD (range: less than 205 ppb to less than 210 ppb). Detection limits are much higher for headspace analysis than for air samples because of the large dilution factors (approximately 300 times) applied to method detection limits.

Real-time Monitoring: Carbon Dioxide (CO_2), Carbon Monoxide (CO), and Total Volatile Organic Compounds (TVOCs), Temperature, and Relative Humidity (RH)

Summaries of real-time monitoring results for CO_2, CO, temperature, and RH are presented in Table A7. Levels of CO_2 and CO were largely consistent across the multiple days of our survey. Levels measured near the Loring roaster ranged from 515 ppm to 4,043 ppm for CO_2 and <0.1 ppm to 3.1 ppm for CO. This location provided the highest peak and average concentrations for both CO_2 and CO.

Summaries of real-time sampling for TVOCs are presented in Table A8. The highest level measured was 4,390 ppb beside the sample roaster, followed by a peak of 1,317 ppb in the café between the espresso grinders. The café espresso grinders provided the highest average TVOC level at 461 ppb measured on day two of our visit.

In addition to the direct reading instruments associated with area samples, we also used the instruments to measure concentrations of CO_2, CO, and TVOCs inside bins of freshly roasted coffee. When the real-time monitors were used in this way, we observed elevated levels of CO_2 (up to 5,490 ppm), CO (up to 473 ppm), and TVOCs (up to 112,262 ppb).

Ventilation Assessment

The entire facility was ventilated with three Carrier 50TC Weathermaker Packaged Rooftop cooling only/electric heat air-handling units (AHUs). During the NIOSH visit, the three AHUs appeared to be functional and well-maintained; however, the ventilation filters were visibly dusty, which can interfere with the performance of the system. The filters should be changed more frequently on a regular schedule (such as monthly or quarterly) to maintain efficiency and proper air flow. A 12.5-ton (cooling) AHU served the production space with a single main supply duct and 19 supply diffusers. The total airflow through this system was measured to be 2,985 cfm, with 445 cfm delivered in the break room and the remaining 2,540 cfm delivered into the larger production space. Return air to the unit was through a single return air duct in the production space directly below the rooftop unit.

The café space was served by a 7.5-ton rooftop AHU supplying 2,585 cfm of air to six supply diffusers above the serving bar area and restroom doors. Return air to the café AHU was through a single return air duct in the production space; no return air was pulled directly from the café space. The third AHU was a smaller 3-ton rooftop unit that served the offices adjacent to the café and quality control area. Air was supplied to each office, and return air was pulled from each space as well. The office closest to the restrooms was supplied 490 cfm of air while only 130 cfm of return air was pulled from the space. The middle office received 615 cfm of supply air with only 305 cfm of return air pulled from the space. The corner office received 365 cfm of supply air with only 35 cfm of return air from the space.

Medical Survey Results

Demographics

Sixteen of 24 employees (67%) at the coffee facility participated in the medical survey. The majority of participants were male (63%) and Caucasian (94%) with a mean age of 31 years and average tenure at the company (including other locations) of 3.7 years. Four participants had worked at one or more of the company's other locations. Six participants (38%) were current or former smokers.

All 16 participants reported working in or entering the production area, ranging from 30 minutes to 40 hours a week. Fifteen reported being within an arm's length of roasted coffee in one or more areas of the production process. Six of 16 reported working in the production area, while the other 10 participants performed activities in the production area as needed.

Symptoms and Self-Reported Diagnoses

The prevalences of symptoms over the last year and last 4 weeks at the time of survey are listed in Table A9. Stuffy, itchy, or runny nose (n=16, 100%) was the most commonly reported symptom followed by watery, itchy eyes (n=9, 56%). One participant reported improvement in eye and nose symptoms away from work; three other participants reported that their nose or eye symptoms were caused or aggravated by dust or specifically green coffee dust.

Six participants reported a diagnosis of eczema, dermatitis, or skin allergy; three reported hay fever or nasal allergies, and three reported history of asthma. Except for one participant with skin issues, all the conditions were diagnosed prior to employment at the coffee processing company. No participants reported a diagnosis of chronic bronchitis, chronic obstructive pulmonary disease, bronchiolitis obliterans, interstitial lung disease, hypersensitivity pneumonitis, chemical pneumonitis, sarcoidosis, heart disease, vocal cord dysfunction, or current asthma.

Six (38%) participants reported one or more lower respiratory symptoms in the past 12 months: wheeze or whistling in chest, breathing trouble, woken with chest tightness, usual cough, or attack of asthma. Of the six, two reported a past physician diagnosis of asthma, two reported hay fever or nasal allergies, and four reported eczema, dermatitis, or skin allergy. Two of the six reported taking medicine for asthma or breathing problems. None of the participants reported improvement in their lower respiratory symptoms away from work or that anything at work caused or aggravated their lower respiratory symptoms.

Medical Tests

Of 16 participants, six (38%) had one or more abnormal breathing tests. One participant had severe airways obstruction and possible small airways abnormality on oscillometry, both improved with bronchodilator. This individual reported rarely having trouble breathing in the past 12 months. S/he also reported a usual cough and wheeze in the past four weeks that did not improve or worsen away from work on days off or on vacation as well as nasal and eye symptoms in the last four weeks that did improve away from work.

Four other participants had abnormalities on impulse oscillometry but normal spirometry. Two of the four with abnormalities on impulse oscillometry had a bronchodilator response. One of the four reported lower respiratory symptoms (e.g., regular trouble breathing, woken by an attack of shortness of breath, wheezing or whistling in chest, attack of asthma) that did not improve or worsen away from work on days off or vacation. This participant's oscillometry showed a possible small airways abnormality that did not improve with bronchodilator. S/he reported no smoking history and taking breathing medication for asthma type symptoms but did not have a physician diagnosis of asthma.

One participant, a former smoker, had an elevated exhaled nitric oxide test; this participant had normal spirometry and oscillometry tests but reported rarely having trouble with breathing in the past 12 months as well as wheeze, chest tightness, and being woken by shortness of breath; these symptoms did not improve or worsen away from work.

NHANES Comparison of Symptoms, Diagnoses, and Spirometry

The SMR for wheeze was elevated at 1.7 (Table A10). SMRs for eye and nose symptoms, sinus problems, phlegm, cough, and physician-diagnosed asthma were not elevated. In addition, there was not an excess of obstructive spirometry abnormalities in comparison to the general U.S. population, adjusted for age distribution, race/ethnicity, sex, and smoking history.

Discussion

Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other chemicals such as CO and CO_2 are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for off-gassing of these chemicals [Anderson et al. 2003; Akiyama et al. 2003; Daglia et al. 2007; Newton 2002; Nishimura et al. 2003; Raffel and Thompson 2013]. While TWA personal and area concentrations of diacetyl and 2,3-pentanedione were low (max 5.9 ppb), peak exposures to alpha-diketones occurred during specific tasks involving the manual handling of roasted coffee beans (e.g., scooping roasted beans from storage bin for weigh/pack and grinding coffee beans).

Alpha-Diketones

Personal Air Sampling

Three of 20 personal full-shift air samples taken inside the facility using standard OSHA methods were above the NIOSH REL for diacetyl. The highest full-shift personal exposure to diacetyl was 5.9 ppb collected from a production employee. This elevated average exposure was likely due to peak exposures that occurred during handling and transferring roasted coffee beans combined with periods of lower exposures. All three of these samples were collected on the same day at the end of the work week. Typically, the company roasted the bulk of their coffee in the beginning of the week. The day we collected these samples, the company was packing and grinding more than the other days in order to get shipments out for delivery and ensure the café had enough roasted beans for the weekend. Since more beans were being ground and packaged, employees were directly handing roasted bean more often, which may have resulted in elevated exposures compared to the other days we were at the facility. All personal full-shift samples were below the NIOSH REL for 2,3-pentanedione.

During our visit, the roaster operator often remained at the roaster control panels, approximately three feet from the roaster. The roasting drum was fully enclosed, and air was exhausted out through the roof, minimizing exposures to coffee emissions. The roasting drum was only opened during the transfer of roasted beans into the cooling drum. The downdraft system on the roaster machines pulled air over the roasted beans and down into the cooling drum to accelerate cooling, which likely decreased the roaster operator's exposure. During our visit, all roasting area samples were below their respective NIOSH RELs indicating the effectiveness of the roaster's downdraft exhaust system. It should be noted NIOSH RELs are specified for personal samples, not area samples.

As noted earlier, the REL should be used as a guideline to indicate when steps should be taken to reduce exposures in the workplace. The risks associated with the measured levels are higher than NIOSH recommends. As described in the quantitative risk assessment from the NIOSH Criteria Document (Table 5-27) [NIOSH 2016], after a 45-year working lifetime exposure to 10 ppb (a concentration slightly higher than the highest concentration measured at this facility) NIOSH estimated less than 2 in 1,000 workers would develop reduced lung function (FEV_1 below the 5th percentile). NIOSH predicted that around 2 in 10,000 workers exposed to diacetyl at 10 ppb would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as at least moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). The effects of a working lifetime exposure at 5.9 ppb would be somewhat close to 5 ppb. NIOSH recommends keeping diacetyl concentrations below 5 ppb because at this level, the risk of reduced lung function after a working lifetime of exposure is below 1 in 1000 workers. NIOSH recommends taking steps to reduce diacetyl exposures to below the REL of 5 ppb whenever possible.

Area Air Sampling

The two area samples that exceeded the NIOSH proposed REL for diacetyl were located in the production area next to the grinder on two separate days. The sample collected on day one (Friday) (9.0 ppb diacetyl; 6.4 ppb 2,3-pentanedione) was slightly higher than the sample collected on day three (Monday) (7.1 ppb diacetyl; 5.9 ppb 2,3-pentanedione). As previously stated, the company was mainly grinding and packaging on Friday in order to get weekend orders out and ensure the café had enough roasted beans for the weekend. The increased surface area due to grinding coffee likely promoted volatile off-gassing and resulted in greater air concentrations of alpha-diketones [Akiyama et al. 2003].

Task-Based Exposures

Coffee processing involves multiple tasks that may cause intermittent exposure to diacetyl and 2,3-pentanedione. Traditional full-shift sampling will not characterize these intermittent, peak exposures. Evaluating intermittent and task-based exposures to diacetyl and 2,3-pentanedione is difficult with current validated sampling methods (OSHA Methods 1013/1016). Since coffee processing tasks are intermittent and short in duration, with some only lasting a few seconds or minutes, we used instantaneous evacuated canisters to sample these shorter tasks and OSHA Methods 1013/1016 for longer duration tasks. We did not collect 15-minute samples at this facility with the intention to compare to the NIOSH STELs; instead, we sampled by task, with varying durations, to understand which tasks may have contributed to higher exposures to diacetyl and 2,3-pentanedione.

Our task-based air sampling revealed that some tasks had higher air concentrations of diacetyl and/or 2,3-pentanedione than other tasks. Using OSHA Method 1013/1016, grinding tasks in the production area resulted in the highest alpha-diketone exposures (Table A2: 65.9 ppb diacetyl; 39.6 ppb 2,3-pentanedione). Since grinding roasted coffee beans is a source of alpha-diketone emissions, the frequency and duration of grinding tasks affects the resultant TWA air concentrations for alpha-diketones. Potentially effective means of mitigating exposure to volatile coffee emissions are to eliminate or reduce grinding of whole beans within the general production area, to install local exhaust ventilation on the grinding equipment, and/or to automate the grinding process to separate the employee from the source of exposure.

Café task-based exposures were generally lower than those in the production area presumably due to the lower amount of coffee handled in the café versus the production area.

Bulk Samples

Diacetyl is not found in green beans and forms later in the coffee roasting process [Daglia et al. 2007]. As expected, we found that roasted coffee emits alpha-diketones (e.g., diacetyl, 2,3-pentanedione) into the headspace of sealed vessels, indicating that roasted coffee is a considerable source of alpha-diketones in the facility. Bulk headspace analysis of roasted coffee beans indicated the presence of diacetyl and 2,3-pentanedione (Table A6). Headspace alpha-diketone concentrations varied by roasting level (i.e., light vs. medium) and origin.

Carbon Monoxide and Carbon Dioxide

CO and CO_2 did not exceed applicable exposure limits. The highest peak levels and average of CO and CO_2 were measured near the Loring roaster. Since roasted coffee is known to emit CO and CO_2, the readings from inside coffee storage bins would presumably be much higher than those measured in the general roasting and packaging space. As a standard work practice, employees should not place their head or face inside the bins or directly outside uncovered bins containing roasted coffee.

Ventilation

The ventilation systems serving the production area, café, and offices seemed to provide adequate total airflow to maintain temperature control during our visit. However, we did not have the equipment to accurately determine the amount of fresh, outdoor air being supplied to each those spaces. Average levels of CO_2 measured in the facility were all 767 ppm or below, which provides an indication that adequate fresh, outdoor air was being provided to the spaces, either through the mechanical ventilation system or open doors and windows.

The air filters in the three rooftop AHUs were all visibly dusty during our visit. Prior to our visit in March 2016, the filters had been last changed on June 25, 2015, according to dates written on the filters themselves. Dirty ventilation filters produce an increase in pressure as air flows through them. This means the fans have to work harder (which requires more energy) to push the same amount of air into the spaces or air flows into the spaces are reduced. To maintain efficient energy use and appropriate air flow rates, the ventilation filters should be changed on a more frequent basis (e.g., monthly or quarterly).

In looking at our sampling results with regard to ventilation, the pre- and post-shift canister samples (see Table A5) taken in March 2016 showed that the concentrations of diacetyl and 2,3-pentanedione increased over the course of the work shift in the production space on day one and in the café on day two. This indicates that the generation rate of these compounds exceeds the rate at which ventilation removes them under the conditions when the samples were taken. Generally, this is undesirable, but the low overall airborne concentrations and the fact that our visit occurred in winter when the facility doors and windows are often more closed were reassuring.

The AHU supplying air to the café pulls all of its return air from the production space instead of the café. This configuration results in airborne contaminants generated in the production space being recycled through the AHU and then distributed to the café space. Essentially, it serves to more evenly distribute contaminants throughout the entire facility. While undesirable at first glance, the low full-shift sampling results for alpha-diketones in the café were reassuring, as they indicated this configuration was not creating excessive worker (or customer) exposures. However, if production increases substantially, exposures in the café should be reassessed to determine if there is a need to prevent migration of air from the production area to the other areas.

Medical Survey

Overall, eye and nose symptoms were the most commonly reported symptoms. Some production employees reported their symptoms were caused or aggravated by dust. Coffee dust is an organic dust known to cause respiratory symptoms [Zuskin et al. 1993; Sakwari et al. 2013]. Green and roasted coffee dust are known risk factors for occupational asthma [Figley and Rawling 1950; Karr et al. 1978; Zuskin et al. 1979, 1985; Thomas 1991]. Persons who become sensitized (develop an immune reaction) to coffee dust can subsequently react to relatively low concentrations in the air. Others may experience irritant-type symptoms from exposure to coffee dust [Oldenburg et al. 2009].

Upper respiratory disease such as allergic rhinitis (hay fever, nasal allergies) and sinusitis are sometimes associated with lower respiratory symptoms and asthma and may precede the diagnosis of asthma [Shaaban et al. 2008; EAACI Task Force on Occupational Rhinitis et al. 2008; Rondón et al. 2012, 2017; Sahay et al. 2016]. Upper respiratory involvement (e.g., rhinitis, sinusitis) can result in suboptimal control of asthma. All six participants that reported lower respiratory symptoms also reported nasal, sinus problems and/or physician-diagnosed hay fever or nasal allergies. Green coffee dust is thought to be a more potent allergen than roasted coffee dust because roasting destroys some of the allergenic activity [Lehrer et al. 1978]. As discussed in the recommendation section, one way to prevent symptoms related to green coffee dust, might be to make N95 disposable filtering facepiece respirators available for voluntary use when emptying burlap bags of green coffee beans into storage containers or cleaning the green bean storage area.

The number of participants with physician-diagnosed asthma was not different from that observed in the U.S. population. Thirty-eight percent of participants reported one or more lower respiratory symptoms in the 12 months prior to the medical survey. None reported improvement in their lower respiratory symptoms when away from the workplace. Asthma symptoms often improve when away from exposures that trigger symptoms while other lung diseases such as obliterative bronchiolitis or COPD generally do not improve. Spirometry can be used to help detect and follow individuals with asthma and other lung diseases such as obliterative bronchiolitis or COPD. Spirometry can show if air is exhaled from the lungs more slowly than normal (i.e., obstructive abnormality) or if the amount of air exhaled is smaller than normal (i.e., restrictive abnormality). In asthma, there is intermittent airways obstruction which is reversible after treatment with bronchodilator medications (e.g., albuterol). In obliterative bronchiolitis, scar tissue prevents the small airways (bronchioles) from opening up when albuterol is given. In other words, the airways obstruction is fixed and not responsive (reversible) to bronchodilator medicine. The obstructed airways prevent rapid emptying of the lung air sacs (alveoli) during exhalation. This explains why the respiratory symptoms of those with occupational obliterative bronchiolitis do not tend to improve when away from work-related exposures; however, avoidance of further exposure can stop progression of the disease [Akpinar-Elci et al. 2004].

Spirometry and impulse oscillometry measure different things. Spirometry assesses airflow and is the breathing test typically used to screen for flavoring-related lung disease. Impulse oscillometry assesses the airways response to a sound or pressure wave and has not commonly been used to screen for flavoring-related lung disease. In general, during the impulse oscillometry test, a small pressure impulse (sound wave) is imposed upon the inspiratory and expiratory airflow during normal tidal breathing. This pressure wave causes a disturbance in the airflow and pressure, and the response of the airways (i.e., change in pressure to change in flow) is a measure of the resistance to airflow in the airways [Desiraju and Agrawal 2016]. Impulse oscillometry may be useful as an indirect measure of airflow obstruction and helpful in individuals not able to perform forced breathing maneuvers that are required during the spirometry test. The impulse oscillometry test has been used for many years to measure changes in the airways of children with lung problems such as asthma and cystic fibrosis [Song et al. 2008; Komarow et al. 2011; Shi et al. 2012; Schulze et al. 2016]. More recently, impulse oscillometry has been used to investigate lung problems in adults exposed to dust or chemicals, such as World Trade Center emergency responders and soldiers returning from deployment overseas [Oppenheimer et al. 2007; Berger et al. 2013; Weinstein et al. 2016]. Over the years, researchers have developed reference (predictive) equations for different populations of children for oscillometry [Malmberg et al. 2002; Park et al. 2011; Lee et al. 2012; de Assumpção et al. 2016]. For adults, there are fewer reference equations available for oscillometry [Vogel and Smidt 1994; Newbury et al. 2008; Schulz et al. 2013]. The predicted values we used for oscillometry measures were based on gender and age according to references values recommended by the manufacturer. Unlike predictive equations used for spirometry, the impulse oscillometry reference equations we used did not take into account height, race, or smoking status [Vogel and Smidt 1994].

Our findings of upper respiratory symptoms caused or aggravated at work or better when away from work in some employees, a 1.7-fold excess of wheeze, and abnormalities on lung function testing in over a third of participants (38%) suggest a burden of respiratory problems in this workforce. The upper respiratory symptoms that were caused or aggravated at work or improved away from work are likely related to workplace exposures. However, the lower respiratory symptoms such as wheeze did not have a work-related pattern. These lower respiratory symptoms and the lung function abnormalities we found could be related to workplace exposures or to other factors. Indeed, employees had respiratory diagnoses that preceded employment at this facility. Because of the small number of participants and the need to protect individuals' privacy, we cannot provide more detailed results that might shed light on possible work-relatedness, such as health measures by job title or task. We mailed each participant their individual lung function test results with an explanation of the results and recommended each participant provide the information to their personal physician.

We recommend starting a medical monitoring program because of the burden of respiratory problems and the employee exposures to diacetyl that exceeded the NIOSH REL. All production employees, any employees that assist with production tasks (e.g., roasting, interacting with open storage bins/containers of roasted coffee, grinding, weighing, or packaging coffee), and café employees should participate in the workplace medical monitoring program. A medical monitoring program is a means of early identification of employees who may be developing lung disease (e.g., asthma, obliterative bronchiolitis) and can help prioritize interventions to prevent occupational lung disease. The NIOSH medical survey results can serve as a baseline for employees who participated. In a workplace with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier. The Centers for Disease Control and Prevention offers tools and resources for setting up a smoking cessation program [CDC 2017b].

Conclusions

Full-shift personal exposures to diacetyl and 2,3-pentanedione were generally below NIOSH RELs at this coffee packaging and roasting facility and café. Diacetyl and 2,3-pentanedione concentrations associated with roasting were low, likely due to the effectiveness of the downdraft exhaust system of the cooling drum and the enclosed roasting machine. We observed higher levels of diacetyl and 2,3-pentanedione during grinding when the physical integrity of the beans was broken, allowing the coffee to release more of these chemicals. Weigh/pack tasks, specifically scooping roasted coffee beans by hand from a storage bin, had the highest measured diacetyl and 2,3-pentanedione exposures, likely due to the close proximity of the employee's breathing zone to the roasted beans. Excluding the results taken directly inside roasted bean storage bins, CO and CO_2 levels were low throughout most of the facility, and the highest CO and CO_2 levels were observed near the roaster machine.

The ventilation systems serving the production area, café, and offices seemed to provide adequate total airflow to maintain temperature control during our visit. However, air concentrations of diacetyl and 2,3-pentanedione increased over the course of the work day in the production area and in the café on the first two days of sampling, indicating that these compounds were being generated faster than the ventilation systems could eliminate them. There were three full-shift personal exposures to diacetyl that exceeded the NIOSH REL of 5 ppb, however all three samples were below 6 ppb. Although we were unable to measure the amount of fresh, outdoor air being supplied to the facility, adjusting the existing air-handling units to consistently bring in more outdoor air will help to dilute alpha-diketones in the air and may help maintain exposures below the REL. For efficient energy use and appropriate air flow rates, the ventilation filters should be changed on a more frequent basis (e.g., monthly or quarterly). A qualified ventilation engineer should be consulted to help with any ventilation modifications. If this does not reduce diacetyl levels below the NIOSH REL, we also suggest installation of local exhaust ventilation where grinding and scooping tasks are being performed to remove contaminants at their source.

Our findings of upper respiratory symptoms that were caused or aggravated at work or better when away from work in some employees, a 1.7-fold excess of wheeze, and abnormalities on lung function testing in over a third of the medical survey participants (38%) suggest a burden of respiratory problems in this workforce. We recommend starting a medical monitoring program because of the burden of respiratory problems and employee exposures to diacetyl that exceeded the NIOSH REL.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage this coffee roasting and packaging facility to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees.

Engineering Controls

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

1. Develop a monthly or quarterly schedule to change filters in the three rooftop AHUs to ensure efficient, more consistent operation.
2. Increase the amount of fresh, outdoor air consistently supplied to the facility by the existing rooftop air-handling units. This will further dilute airborne contaminants and may help maintain personal alpha-diketone exposures below the NIOSH RELs. Consult with a qualified ventilation engineer to determine options and appropriate outdoor air flow requirements.
3. If other engineering and administrative controls (see below) do not reduce air concentrations of alpha-diketones below the NIOSH REL, work with a ventilation engineer to install local exhaust ventilation during the following tasks:
    a. grinding roasted coffee;
    b. scooping roasted coffee by hand from storage bins;
    c. weighing and packaging roasted coffee, and
4. Conduct follow-up personal air sampling on employees with primary duties in the production area to verify that the modifications have been effective in reducing alpha-diketone exposures to below the recommended exposure limits.

Administrative Controls

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

1. Continue to cover bins of roasted beans to reduce the overall emission of alpha-diketones and other chemicals (e.g., CO, CO_2) into the workplace and lower worker exposure.
2. Avoid placing head and face near or inside roasted bean bins to reduce exposure to VOCs, CO, and CO_2.
3. Whenever feasible, do not blend roasted beans by hand. Instead use the agitator of the cooling drum or some other automatic mechanism that minimizes employee contact with roasted beans during blending.
4. Periodically clean the roaster's exhausts in accordance with manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve the efficiency, energy usage, and roaster performance.
5. Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, CO, CO_2, dust) in the workplace and how to protect themselves. OSHA's *Hazard Communication Standard*, also known as the "*Right to Know Law*" [29 CFR 1910.1200] requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.
6. Ensure employees are educated to consider the risks of further exposure if they develop lower respiratory symptoms (e.g., cough, shortness of breath, wheezing) that are progressive and severe in degree. Employees should report new, persistent, or worsening symptoms to their personal healthcare providers and to a designated individual at this workplace. Employees with new, persistent, or worsening symptoms should share this report with their healthcare providers.

Personal Protective Equipment

The effectiveness of personal protective equipment in the form of respiratory protection in controlling respiratory exposures depends on avoiding breakdowns in implementation that result in insufficient protection. Proper use of respiratory protection (respirators) requires a comprehensive respiratory protection program and a high level of employee and management involvement and commitment to assure that the right type of respirator is chosen for each hazard, respirators fit users and are maintained in good working order, and respirators are worn when they are needed. Supporting programs such as training, change-out schedules, and medical assessment may be necessary. Respirators should not be the sole method for controlling hazardous inhalation exposures. Rather, respirators should be used until effective engineering and administrative controls are in place.

1. In addition to engineering and administrative controls, respiratory protection is a potential option to further reduce exposures to alpha-diketones (e.g., diacetyl and 2,3-pentanedione). If respiratory protection is used, NIOSH-certified respirators should be fitted with organic vapor cartridges and particulate filters. The choice of respirator should be guided by personal exposure sampling for diacetyl and 2,3-pentanedione

[NIOSH 2004]. Respirators have assigned protection factors (APFs). APF refers to the highest level of protection a properly selected respirator can provide. For instance, air-purifying half-face respirators have an assigned protection factor (APF) of 10, and air-purifying full-face respirators have an APF of 50. Also, there are powered-air purifying respirators that have APFs of 25, 50, or 1000. The OSHA APFs can be found in Table 1 of OSHA Respiratory Protection Standard at https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716.

If mandatory respiratory protection is used, a written respiratory protection program should be implemented as required by the OSHA Respiratory Protection Standard (29 CFR 1910.134), including training, fit testing, maintenance and use requirements.

2. Offer employees the voluntary use of N95 disposable filtering facepiece respirators when working with green beans and chaff such as emptying burlap bags of green beans into the storage silos, cleaning the exhaust system of chaff, emptying the chaff containers, or cleaning the green bean storage area. N95 respirators should be available in various sizes, and each potential N95 user should receive a copy of Appendix D of the OSHA Respiratory Protection Standard (http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9784). Information about Appendix D and voluntary use of respirators can be found on the OSHA website at https://www.osha.gov/video/respiratory_protection/voluntaryuse_transcript.html

   Please be aware that N95s are not protective against alpha-diketones (diacetyl, 2,3-pentanedione, or 2,3-hexanedione). In cases of dual exposure to dust and alpha-diketones, NIOSH-certified organic vapor cartridges (for the alpha-diketones) and particulate cartridges/filters (for the dust) would be warranted.

Medical Monitoring

The purpose of a medical monitoring program is to help assure the health of employees who have workplace exposures (e.g., diacetyl, 2,3-pentanedione, green coffee beans/dust) known to pose risk for potentially serious health conditions such as asthma or obliterative bronchiolitis.

1. Institute a medical monitoring program for employees who work or assist in the production area and in the café. The medical monitoring should consist of evaluation with a questionnaire (to obtain health and work task information) and spirometry (to assess lung function) at baseline and at one year to monitor for respiratory symptoms and to establish employees' baseline in lung function and any abnormal decline in lung function in the first year. Subsequently, an annual questionnaire evaluation should occur to monitor for respiratory symptoms. New or worsening respiratory symptoms should prompt additional evaluation including spirometry. Details about spirometry and a medical monitoring program can be found in chapter 9 of the NIOSH Criteria Document [NIOSH 2016].
2. If an employee is identified as likely having lung disease from exposure to diacetyl or 2,3-pentanedione, it should be viewed as a sentinel event indicating that there was a breakdown in exposure controls and that there is potential risk for co-workers. Should

this occur, the unanticipated source of exposure must be identified and brought under control. In addition, increased intensity of medical surveillance would be required for all employees performing similar job tasks or having similar or greater potential for exposure. The NIOSH Criteria Document provides detailed guidance on responses to such sentinel events [NIOSH 2016].

Smoking Cessation Program

In a workplace with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier. We recommend implementing a smoking cessation program to assist employees to stop smoking. The Centers for Disease Control and Prevention offers tools and resources for setting up a smoking cessation program [CDC 2017b].

Appendix A: Tables

Table A1. OSHA Method 1013/1016 full-shift personal and area air sampling results by location, NIOSH industrial hygiene survey, March 2016.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	All Over	2	0 (0%)	<0.4	<0.4	0
Diacetyl	Personal	Café	3	3 (100%)	1.3	2.7	0
Diacetyl	Personal	Office Area	1	0 (0%)	<0.4	<0.4	0
Diacetyl	Personal	Production Area	9	9 (100%)	2.8	5.9	2
Diacetyl	Personal	Quality Control	1	1 (100%)	2.1	2.1	0
Diacetyl	Personal	Roasting	4	4 (100%)	2.6	5.8	1
Diacetyl	Area	Café	9	7 (78%)	<0.3	3.7	N/A
Diacetyl	Area	Office Area	3	2 (67%)	<0.4	2.2	N/A
Diacetyl	Area	Production Area	21	18 (86%)	<0.3	9.0	N/A
Diacetyl	Area	Quality Control	3	1 (33%)	<0.4	1.1	N/A
2,3-Pentanedione	Personal	All Over	2	2 (100%)	1.1	1.3	0
2,3-Pentanedione	Personal	Café	3	3 (100%)	1.6	2.4	0
2,3-Pentanedione	Personal	Office Area	1	1 (100%)	0.9	0.9	0
2,3-Pentanedione	Personal	Production Area	9	9 (100%)	2.2	5.2	0
2,3-Pentanedione	Personal	Quality Control	1	1 (100%)	2.0	2.0	0
2,3-Pentanedione	Personal	Roasting	4	4 (100%)	2.4	4.1	0
2,3-Pentanedione	Area	Café	9	8 (89%)	<0.3	3.7	N/A
2,3-Pentanedione	Area	Office Area	3	3 (100%)	0.7	1.9	N/A
2,3-Pentanedione	Area	Production Area	21	20 (95%)	<0.3	6.4	N/A
2,3-Pentanedione	Area	Quality Control	3	3 (100%)	1.1	2.0	N/A
2,3-Hexanedione	Personal	All Over	2	0 (0%)	<0.4	<0.5	-
2,3-Hexanedione	Personal	Café	3	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Office Area	1	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Production Area	9	0 (0%)	<0.4	<0.5	-
2,3-Hexanedione	Personal	Quality Control	1	0 (0%)	<0.4	<0.4	-

Table A1 (continued). OSHA Method 1013/1016 full-shift personal and area air sampling results by location, NIOSH industrial hygiene survey, March 2016.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
2,3-Hexanedione	Personal	Roasting	4	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Café	9	0 (0%)	<0.4	<0.5	-
2,3-Hexanedione	Area	Office Area	3	0 (0%)	<0.5	<0.6	-
2,3-Hexanedione	Area	Production Area	21	0 (0%)	<0.4	<0.6	-
2,3-Hexanedione	Area	Quality Control	3	0 (0%)	<0.4	<0.5	-

Note: NIOSH=National Institute for Occupational Safety and Health; OSHA=Occupational Safety and Health Administration; N=number of samples; Above LOD N (%)=number and percentage of samples above limit of detection (LOD); < indicates below the limit of detection; Above REL N=number of samples above the NIOSH recommended exposure limit (REL); ppb=parts per billion; N/A indicates that NIOSH RELs are specified for personal air samples, and cannot be directly applied to area air samples; "-" indicates that there is currently no REL for 2,3-hexanedione. ; "All Over" location includes employees that were cross-trained and performed tasks at different areas.

Table A2. OSHA Method 1013/1016 task-based personal air sampling results, NIOSH industrial hygiene survey, March 2016.

Analyte	Work Area	Job Title	Task Description	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (minutes) Sampling Duration (range)
Diacetyl	Café	Barista	Grind coffee beans	1	1 (100%)	1.4	1.4	- (15)
Diacetyl	Café	Barista	Making coffee	2	2 (100%)	3.1	14.9	15 (14-15)
Diacetyl	Café	Barista	Making espresso	3	2 (67%)	<=3.5	3.7	9 (5-15)
Diacetyl	Café	Barista	Misc. café tasks	2	1 (50%)	<1.3	2.5	15 (14-15)
Diacetyl	Production Area	Production	Grind coffee beans	7	5 (71%)	<1.3	65.9	8 (3-15)
Diacetyl	Production Area	Production	Package coffee	8	5 (63%)	<=1.7	10.8	12 (0-16)
Diacetyl	Production Area	Roaster	Cleaning Roaster	3	2 (67%)	<0.7	2.7	19 (18-20)
Diacetyl	Production Area	Roaster	Quality Control	3	0 (0%)	<1.3	<1.4	15 (14-15)
Diacetyl	Production Area	Roaster	Roast coffee beans	6	1 (17%)	<0.9	2.2	14 (12-16)
Diacetyl	Quality Control	Quality Control	Quality Control	2	0 (0%)	<1.3	<1.3	15 (15-15)
Diacetyl	Quality Control	Quality Control Roaster	Quality Control	3	0 (0%)	<0.9	<1.3	15 (15-15)
Diacetyl	Roasting	Roaster	Quality Control	3	0 (0%)	<1.1	<1.3	16 (15-18)
2,3-Pentanedione	Café	Barista	Grind coffee beans	1	1 (100%)	1.5	1.5	- (15)
2,3-Pentanedione	Café	Barista	Making coffee	2	2 (100%)	2.2	10.6	15 (14-15)
2,3-Pentanedione	Café	Barista	Making espresso	3	2 (67%)	<=2.4	3.4	9 (5-15)
2,3-Pentanedione	Café	Barista	Misc. café tasks	2	2 (100%)	1.4	2.7	15 (14-15)
2,3-Pentanedione	Production Area	Production	Grind coffee beans	7	6 (86%)	<=3.5	39.6	8 (3-15)
2,3-Pentanedione	Production Area	Production	Package coffee	8	8 (100%)	1.9	10.3	12 (0-16)
2,3-Pentanedione	Production Area	Roaster	Cleaning Roaster	3	2 (67%)	<0.7	5.6	19 (18-20)
2,3-Pentanedione	Production Area	Roaster	Quality Control	3	3 (100%)	2.1	2.7	15 (14-15)
2,3-Pentanedione	Production Area	Roaster	Roast coffee beans	6	6 (100%)	2.4	7.9	14 (12-16)
2,3-Pentanedione	Quality Control	Quality Control	Quality Control	2	2 (100%)	2.6	3.3	15 (15-15)
2,3-Pentanedione	Quality Control	Quality Control Roaster	Quality Control	3	3 (100%)	1.7	7.1	15 (15-15)
2,3-Pentanedione	Roasting	Roaster	Quality Control	3	3 (100%)	1.4	3.2	16 (15-18)

Table A2 (continued). OSHA Method 1013/1016 task-based personal air sampling results, NIOSH industrial hygiene survey, March 2016.

Analyte	Work Area	Job Title	Task Description	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (minutes) Sampling Duration (range)
2,3-Hexanedione	Café	Barista	Grind coffee beans	1	0 (0%)	<1.4	<1.4	- (15)
2,3-Hexanedione	Café	Barista	Making coffee	2	0 (0%)	<1.4	<1.5	15 (14-15)
2,3-Hexanedione	Café	Barista	Making espresso	3	0 (0%)	<1.4	<4.3	9 (5-15)
2,3-Hexanedione	Café	Barista	Misc. café tasks	2	0 (0%)	<1.4	<1.5	15 (14-15)
2,3-Hexanedione	Production Area	Production	Grind coffee beans	7	0 (0%)	<1.4	<7.1	8 (3-15)
2,3-Hexanedione	Production Area	Production	Package coffee	8	0 (0%)	<1.3	<2.6	12 (0-16)
2,3-Hexanedione	Production Area	Roaster	Cleaning Roaster	3	0 (0%)	<1.0	<1.1	19 (18-20)
2,3-Hexanedione	Production Area	Roaster	Quality Control	3	0 (0%)	<1.4	<1.5	15 (14-15)
2,3-Hexanedione	Production Area	Roaster	Roast coffee beans	6	0 (0%)	<1.3	<1.7	14 (12-16)
2,3-Hexanedione	Quality Control	Quality Control	Quality Control	2	0 (0%)	<1.4	<1.4	15 (15-15)
2,3-Hexanedione	Quality Control	Quality Control Roaster	Quality Control	3	0 (0%)	<1.4	<1.4	15 (15-15)
2,3-Hexanedione	Roasting	Roaster	Quality Control	3	0 (0%)	<1.2	<1.4	16 (15-18)

Note: NIOSH=National Institute for Occupational Safety and Health; OSHA=Occupational Safety and Health Administration; N=number of samples; Above LOD N (%)=number and percentage of samples above limit of detection (LOD); ppb=parts per billion; < indicates below the limit of detection; <= indicates less than or equal to the limit of detection.

Table A3. Instantaneous* evacuated canister task-based air sampling results, NIOSH industrial hygiene survey, March 2016.

Task Location	Task Description	Diacetyl Concentration (ppb)	2,3-Pentanedione Concentration (ppb)	2,3-Hexanedione Concentration (ppb)
Café	Grinding for customer order	13.3	12.1	2.7
Café	Grinding for customer order	3.7	2.4	<0.9
Café	Making pour over for customer order	7.2	5.6	<1.0
Café	Making pour over for customer order	10.4	10.1	1.5
Production Area	Opening roaster door to empty roasted beans into cooling drum	6.4	5.2	3.5
Production Area	Opening cooling drum door to empty roasted beans into storage bin	5.1	6.5	3.5
Production Area	Scooping roasted beans from storage bin for weigh/pack (decaf Mexico)	151	182	2.7
Production Area	Scooping roasted beans from storage bin for weigh/pack (Peru)	106	51.3	7.0
Production Area	Scooping roasted beans from storage bin for weigh/pack (Colombia)	77.1	92.3	2.3
Production Area	Scooping roasted beans from storage bin for weigh/pack (light Sumatra)	67.1	60.4	4.5
Production Area	Scooping roasted beans from storage bin for weigh/pack (Brazil)	6.8	5.6	1.4
Production Area	Scooping roasted beans from storage bin for weigh/pack (medium Sumatra)	5.7	3.6	3.0
Production Area	Grinding (breakfast blend; medium Guatemala)	30.2	30.6	3.1
Quality Control	Cupping fresh espresso grinds	101	149	7.5
Quality Control	Cupping brewed espresso	8.6	10.2	3.4
Quality Control	Grinding 13 grams of espresso	59.1	61.3	6.4

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection; task-based air samples were collected by placing the inlet of the flow controller at the employee's personal breathing zone as he/she performed their work task to replicate exposure.
***sampling duration approximately 30 seconds;**

Table A4. Instantaneous* evacuated canister source air sampling results, NIOSH industrial hygiene survey, March 2016.

Work Area	Source Description	Diacetyl Concentration (ppb)	2,3-Pentanedione Concentration (ppb)	2,3-Hexanedione Concentration (ppb)
Production Area	Grinding breakfast blend	93.5	48.8	<0.9
Production Area	Grinding one pound of Change Maker and decaf Harmony blend	652	408	<1.1
Production Area	Roasted bean storage bin (Brazil)	13.0	10.3	<0.9
Production Area	Roasted bean storage bin (Brazil)	18.1	20.0	<1.0
Production Area	Roasted bean storage bin (Costa Rica)	4.6	4.7	<0.9
Production Area	Roasted bean storage bin (Costa Rica)	6.1	5.4	<1.0
Production Area	Roasted bean storage bin (Rwanda)	226	125	<0.9
Quality Control	Above sample roaster cooling tray	62.6	37.6	4.7
Quality Control	Above sample roaster cooling tray	46.4	29.7	5.7
Quality Control	At sample roaster door	4.5	1.0	<1.0
Quality Control	At sample roaster door	243	133	8.8
Quality Control	Making a shot of espresso	57.9	66.9	4.1
Quality Control	Making a shot of espresso	12.5	11.7	1.8
Quality Control	Grinding 5 pound house blend	1079	855	20.3
Quality Control	Grinding 13 grams espresso blend	7.4	7.0	5.4
Quality Control	Grinding 13 grams espresso blend	7.5	6.5	3.4
Quality Control	Grinding 13 grams espresso blend	69.7	80.5	5.5
Quality Control	Espresso disposal container	95.9	105.2	4.6
Quality Control	Pouring of espresso	7.0	6.1	3.5
Roasting	At roaster door	5.6	4.4	2.1
Roasting	At roaster door	4.8	5.7	2.9
Roasting	At roaster door to cooling drum	3.1	1.6	<1.2
Roasting	Transfer of beans from cooling bin to container	3.6	2.1	<0.9
Roasting	Transfer of beans from cooling bin to container	4.2	3.6	3.7

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection.
***sampling duration approximately 30 seconds.**

Table A5. Instantaneous* evacuated canister pre-and-post shift background air sampling results, NIOSH industrial hygiene survey, March 2016.

Day	Work Area	Shift	Diacetyl Concentration (ppb)	2,3-Pentanedione Concentration (ppb)	2,3-Hexanedione Concentration (ppb)
3/4/2016	Production	Pre	1.9	1.4	<0.6
3/4/2016	Production	Post	3.6	2.9	0.8
3/5/2016	Cafe	Pre	1.3	0.9	<0.6
3/5/2016	Cafe	Post	2.0	1.6	<0.6
3/7/2016	Production	Pre	2.6	1.3	0.8
3/7/2016	Production	Post	2.5	1.3	<0.6

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection.
***sampling duration approximately 30 seconds.**

Table A6. Headspace analysis of bulk roasted coffee bean samples, NIOSH industrial hygiene survey, March 2016.

Bulk Sample Origin (Roast)	Diacetyl Concentration (ppb)	2,3-Pentanedione Concentration (ppb)	2,3-Hexanedione Concentration (ppb)
Rwanda	1312	1655	<207
Sumatra (light-medium)	527	839	<210
South and Central America (Espresso blend)	189	269	<205
South and Central American (light and medium blend)	999	1236	<207
Mexico	801	1232	<209
Sumatra (light)	549	936	<208
Sumatra (medium)	669	855	<208
Decaf Brazil	884	1493	<207

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates less than the limit of detection.

Table A7. Real-time carbon dioxide, carbon monoxide, temperature, and relative humidity monitoring, NIOSH industrial hygiene survey, March 2016.

Day	Work Area	Area sample location	Measurement	Minimum	Maximum	Average
One	Production	Roaster machine	CO_2 (ppm)	515	4043	767
			CO (ppm)	<0.1	3.1	0.8
			Temperature (°F)	68	79	72
			Relative Humidity (%)	14	29	21
Two	Café	Between main entrance and stage	CO_2 (ppm)	535	1236	733
			CO (ppm)	<0.1	1.1	0.1
			Temperature (°F)	69	72	71
			Relative Humidity (%)	24	34	27
Three	Café	Between main entrance and stage	CO_2 (ppm)	473	817	586
			CO (ppm)	<0.1	1.1	0.3
			Temperature (°F)	61	72	70
			Relative Humidity (%)	30	47	32
Three	Production	Entrance into café	CO_2 (ppm)	501	1082	593
			CO (ppm)	<0.1	0.6	0.1
			Temperature (°F)	68	70	69
			Relative Humidity (%)	33	40	36
Three	Production	Middle of roasted bean storage bins	CO_2 (ppm)	530	691	580
			CO (ppm)	<0.1	1.5	0.3
			Temperature (°F)	69	72	71
			Relative Humidity (%)	36	40	36
Three	Production	Beside sample roaster	CO_2 (ppm)	490	647	557
			CO (ppm)	<0.1	1.4	0.1
			Temperature (°F)	71	103	72
			Relative Humidity (%)	35	45	39
Four	Café	Between espresso grinders	CO_2 (ppm)	535	1008	666
			CO (ppm)	<0.1	1.2	0.3
			Temperature (°F)	70	76	74
			Relative Humidity (%)	40	48	42

Note: NIOSH=National Institute for Occupational Safety and Health; ppm=parts per million; °F=degrees Fahrenheit; %=percent; CO=carbon monoxide; CO_2=carbon dioxide; < indicates less than resolution of instrument.

Table A8. Real-time total volatile organic compound monitoring, NIOSH industrial hygiene survey, March 2016.

Day	Work Area	Area sample location	Minimum (ppb)	Maximum (ppb)	Average (ppb)
One	Production	Roaster machine	207	813	420
Two	Café	Between main entrance and stage	113	934	280
Two	Café	Between espresso grinders	93	1317	461
Three	Production	Middle of roasted bean storage bins	106	623	217
Three	Production	Beside sample roaster	99	4390	177
Three	Production	Right side of Loring roaster cooling bin	178	642	303
Four	Production	Right side of Loring roaster cooling bin	64	963	331
Four	Café	Between espresso grinders	34	584	214

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion.

Table A9. Prevalence of reported symptoms, NIOSH medical survey, March 2016

Symptom	Experienced in the last 12 months N = 16 Number (%)	Experienced in the last 4 weeks N = 16 Number (%)
Nose symptoms*	16 (100%)	6 (38%)
Eye symptoms†	9 (56%)	6 (38%)
Sinusitis or sinus problems	5 (31%)	2 (13%)
Problem with ability to smell	3 (19%)	-
Phlegm on most days for 3 months	1 (6%)	-
Lower respiratory symptoms (reported at least one of the following)	6 (38%)	3 (19%)
Chest wheezing or whistling	6 (38%)	1 (6%)
SOB on level ground or walking up a slight a hill	0	0
Breathing trouble	5 (31%)	2 (13%)
Awoke with chest tightness	2 (13%)	0
Awoke with shortness of breath	3 (16%)	0
Usual cough‡	1 (6%)	1 (6%)
Asthma attack	1 (6%)	0
Systemic symptoms (reported at least one of the following)	9 (56%)	3 (19%)
Flu-like achiness or achy joints	8 (50%)	2 (13%)
Fever or chills	6 (38%)	1 (6%)
Unusual tiredness or fatigue	4 (25%)	3 (19%)

Note: NIOSH=National Institute for Occupational Safety and Health; N=number of participants; SOB=shortness of breath; "-"= A four week question was not asked for the symptom.
***Nose symptoms includes one or both of the following: 1) stuffy, itchy, or runny nose or 2) stinging, burning nose.**
†Eye symptoms includes one or both of the following: 1) watery, itchy eyes or 2) stinging, burning eyes.
‡‡This question did not specifically ask about a cough within the past 12 months; participants were asked, "Do you usually have a cough?" If the participants answered yes to that question, they were then asked, "Have you had a cough at any time in the last 4 weeks?"

Table A10. Adjusted* comparisons of symptoms and self-reported physician diagnosis among NIOSH medical survey participants (N=16) to US adult population March 2016

Health condition	Comparative population†	Observed Number	Expected Number	SMR (95% CI)‡
Watery, itchy eyes last 12 months	NHANES III	9	7.0	1.3 (0.7-2.5)
Stuffy, itchy, or runny nose last 12 months	NHANES III	16	10.1	1.6 (1.0-2.6)
Sinus problems last 12 months	NHANES III	5	6.1	0.8 (0.4-1.9)
Phlegm 3 consecutive month or more	NHANES III	1	0.8	1.3 (0.2-7.2)
Wheeze last 12 months	**NHANES 2007-2012**	**6**	**1.7**	**3.5 (1.6-7.7)**
Cough 3 consecutive months or more	NHANES III	1	0.8	1.3 (0.2-7.3)
Ever asthma (physician-diagnosed)	NHANES 2007-2012	3	2.5	1.2 (0.4-3.6)

Note: NIOSH=National Institute for Occupational Safety and Health; NHANES=National Health and Nutrition Examination Survey; SMR=standardized morbidity ratio.
***Adjusted for sex, race/ethnicity, age, and smoking categories.**
†We used the most recent NHANES survey available for each comparison.
‡95% confidence intervals (CIs) that exclude one are statistically significantly different from comparison with US adult population and are shown in bold.

References

ACGIH (American Conference of Governmental Industrial Hygienists) [2017a]. 2017 TLVs® and BEIs®: Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACGIH [2017b]. Chemicals Substances and Other Issues Under Study (TLV®-CS). Available at: http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list/chemical-substances-and-other-issues-under-study-tlv. Date accessed: November 2017.

Akiyama M, Murakami K, Ohtani N, Iwatsuki K, Sotoyama K, Wada A, Tokuno K, Iwabuchi H, Tanaka K [2003]. Analysis of volatile compounds released during the grinding of roasted coffee beans using solid-phase microextraction. J Agric Food Chem *51*(7):1961-1969.

Akpinar-Elci M, Travis WD, Lynch DA, Kreiss K [2004]. Bronchiolitis obliterans syndrome in popcorn production plant workers. Eur Respir J *24*(2):298-302.

Anderson BA, Shimoni E, Liardon R, Labuza P [2003]. The diffusion kinetics of carbon dioxide in fresh roasted and ground coffee. J Food Eng *59*:71-78.

Bailey RL, Cox-Ganser JM, Duling MG, LeBouf RF, Martin SB Jr, Bledsoe TA, Green BJ, Kreiss K [2015]. Respiratory morbidity in a coffee processing workplace with sentinel obliterative bronchiolitis cases. Am J Ind Med *58*(12):1235-1245.

Berger KI, Reibman J, Oppenheimer BW, Vlahos I, Harrison D, Goldring RM [2013]. Lessons from the World Trade Center disaster: airway disease presenting as restrictive dysfunction. Chest *144*(1):249-257.

Burney P, Chinn S [1987]. Developing a new questionnaire for measuring the prevalence and distribution of asthma. Chest *91* (6 Suppl):79S-83S.

Burney PG, Laitinen LA, Perdrizet S, Huckauf H, Tattersfield AE, Chinn S, Poisson N, Heeren A, Britton JR, Jones T [1989]. Validity and repeatability of the IUATLD (1984) Bronchial symptoms questionnaire: an international comparison. Eur Respir J *2*(10):940-945.

Burney PG, Luczynska C, Chinn S, Jarvis D [1994]. The European community respiratory health survey. Eur Respir J *7*(5):954-960.

CDC (Centers for Disease Control and Prevention) [1996]. Third National Health and Nutrition Examination Survey, 1988–1994, NHANES III Examination Data File [CDROM]. Hyattsville, Maryland: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. (Public use data file documentation No. 76300.)

CDC [2013a]. Obliterative bronchiolitis in workers in a coffee-processing facility—Texas, 2008–2012. Morb Mortal Wkly Rep *62*(16):305–307.

CDC [2013b]. Carbon monoxide. Available at: https://www.cdc.gov/niosh/topics/co-comp/default.html. Date accessed: November 2017

CDC [2017a]. National Center for Health Statistics. National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2007-2012] Available at: https://wwwn.cdc.gov/nchs/nhanes/default.aspx. Accessed: November 2017.

CDC [2017b]. Smoking & tobacco use: quit smoking. Available at: https://www.cdc.gov/tobacco/stateandcommunity/tobacco_control_programs/index.htm. Date accessed: November 2017

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Cockcroft D, Davis B [2009]. Direct and indirect challenges in the clinical assessment of asthma. Ann Allergy Asthma Immunol *103*(5):363-369.

Daglia M, Papetti A, Aceti C, Sordelli B, Spini V, Gazzani G [2007]. Isolation and determination of α-dicarbonyl compounds by RP-HPLC-DAD in green and roasted coffee. J Agric and Food Chem *55*(22):8877-8882.

Day G, LeBouf R, Grote A, Pendergrass S, Cummings K, Kreiss K, and Kullman G [2011]. Identification and measurement of diacetyl substitutes in dry bakery mix production. J Occup Environ Hyg *8*(2):93-103.

de Assumpção MS, Gonçalves RM, Martins R, Bobbio TG, Schivinski CI [2016]. Reference Equations for Impulse Oscillometry System Parameters in Healthy Brazilian Children and Adolescents. Respir Care *61*(8):1090-1099.

Desiraju K, Agrawal A [2016]. Impulse oscillometry: The state-of-art for lung function testing. Lung India *33*(4):410-416.

Duling MG, LeBouf RF, Cox-Ganser JM, Kreiss K, Martin SB Jr, Bailey RL [2016]. Environmental characterization of a coffee processing workplace with obliterative bronchiolitis in former workers. J Occup Environ Hyg *13*(10):770-781.

Dweik RA, Boggs PB, Erzurum SC, Irvin CG, Leigh MW, Lundberg JO, Olin AC, Plummer AL, Taylor DR; 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*(5):602-615.

EAACI Task Force on Occupational Rhinitis, Moscato G, Vandenplas O, Gerth Van Wijk R, Malo JL, Quirce S, Walusiak J, Castano R, De Groot H, Folletti I, Gautrin D, Yacoub MR, Perfetti L, Siracusa A [2008]. Occupational rhinitis. Allergy *63*(8):969-980.

Ferris BG [1978]. Epidemiology standardization project. Am Rev Respir Dis *118*(Suppl):1–53.

ECRHS (European Community Respiratory Health Survey) [2014]. Questionnaires, protocols and instructions. Available at: http://www.ecrhs.org/Quests.htm. Date accessed: November 2017.

Figley KD, Rawling FF [1950] Castor bean: an industrial hazard as a contaminant of green coffee dust and used burlap bags. J Allergy *21*:545–553.

Ghanei M, Tazelaar HD, Chilosi M, Harandi AA, Peyman M, Akbari HM, Shamsaei H, Bahadori M, Aslani J, Mohammadi A [2008]. An international collaborative pathologic study of surgical lung biopsies from mustard gas-exposed patients. Respir Med *102*(6):825-30.

Grassi M, Rezzani C, Biino G, Marinoni A [2003]. Asthma-like symptoms assessment through ECRHS screening questionnaire scoring. J Clin Epidemiol *56*(3):238–247.

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*(1):179-187.

Henneberger PK Redlich CA, Callahan DB, Harber P, Lemière C, Martin J, Tarlo SM, Vandenplas O, Torén K; ATS Ad Hoc Committee on Work-Exacerbated Asthma [2011]. An official American Thoracic Society statement: work-exacerbated asthma. Am J Respir Crit Care Med *184*(3):368–378.

Hubbs AF, Cumpston AM, Goldsmith WT, Battelli LA, Kashon ML, Jackson MC, Frazer DG, Fedan JS, Goravanahally MP, Castranova V, Kreiss K, Willard PA, Friend S, Schwegler-Berry D, Fluharty KL, Sriram K [2012]. Respiratory and olfactory cytotoxicity of inhaled 2,3-pentanedione in Sprague-Dawley rats. Am J Pathol *181*(3):829-844.

Kanwal R, Kullman G, Piacitelli C, Boylstein R, Sahakian N, Martin S, Fedan K, Kreiss K [2006]. Evaluation of flavorings-related lung disease risk at six microwave popcorn plants. J Occup Environ Med *48*(2):149-57.

Karr RM, Davies RJ, Butcher BT, Lehrer SB, Wilson MR, Dharmarajan V, Salvaggio JE [1978]. Occupational asthma. J Allergy Clin Immunol *61*(1):54–65.

Kim TJ, Materna BL, Prudhomme JC, Fedan KB, Enright PL, Sahakian NM, Windham GC, Kreiss K [2010]. Industry-wide medical surveillance of California flavor manufacturing workers: Cross-sectional results. Am J Ind Med *53*(9):857-865.

King MS, Eisenberg R, Newman JH, Tolle JJ, Harrell FE Jr, Nian H, Ninan M, Lambright ES, Sheller JR, Johnson JE, Miller RF [2011]. Constrictive bronchiolitis in soldiers returning from Iraq and Afghanistan. N Engl J Med *365*(3):222-230.

Kreiss K [2013]. Occupational causes of constrictive bronchiolitis. Curr Opin Allergy Clin Immunol *13*(2):167-172.

Komarow HD, Myles IA, Uzzaman A, Metcalfe DD [2011]. Impulse oscillometry in the evaluation of diseases of the airways in children. Ann Allergy Asthma Immunol *106*(3):191-199.

Langford NJ [2005]. Carbon dioxide poisoning. Toxicol Rev *24*(4):229-235.

LeBouf RF, Stefaniak AB, Virji, MA [2012]. Validation of evacuated canisters for sampling volatile organic compounds in healthcare settings. J Environ Monit *14*(3):977–983.

LeBouf RF and Simmons M [2017]. Increased sensitivity of OSHA method analysis of diacetyl and 2,3-pentanedione in air. J Occup Environ Hyg *14*(5):343-348.

Lee JY, Seo JH, Kim HY, Jung YH, Kwon JW, Kim BJ, Kim HB, Lee SY, Jang GC, Song DJ, Kim WK, Shim JY, Kim HJ, Shin YJ, Park JW, Cho SH, Lee JS, Hong SJ [2012]. Reference values of impulse oscillometry and its utility in the diagnosis of asthma in young Korean children. J Asthma *49*(8):811-816.

Lehrer SB, Karr RM, Salvaggio JE [1978]. Extraction and analysis of coffee bean allergens. Clin Allergy *8*(3):217-226.

Malmberg LP, Pelkonen A, Poussa T, Pohianpalo A, Haahtela T, Turpeinen M [2002]. Determinants of respiratory system input impedance and bronchodilator response in healthy Finnish preschool children. Clin Physiol Funct Imaging *22*(1):64-71.

Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Crapo R, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johnson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J, ATS/ERS Task Force [2005]. Standardisation of spirometry. Eur Respir J *26*(2):319-338.

Morgan DL, Jokinen MP, Price HC, Gwinn WM, Palmer SM, Flake GP [2012]. Bronchial and bronchiolar fibrosis in rats exposed to 2,3-pentanedione vapors: implications for bronchiolitis obliterans in humans. Toxicol Pathol *40*(3):448-465.

Morgan DL, Jokinen MP, Johnson CL, Price HC, Gwinn WM, Bousquet RW, Flake GP [2016]. Chemical reactivity and respiratory toxicity of the α-diketone flavoring agents: 2,3-butanedione, 2,3-pentanedione, and 2,3-hexanedione. Toxicol Pathol *44*(5):763–783.

Newbury W, Crockett A, Newbury J [2008]. A pilot study to evaluate Australian predictive equations for the impulse oscillometry system. Respirology *13*(7):1070-1075.

Newton J [2002]. Carbon monoxide exposure from coffee roasting. Appl Occup Environ Hyg *17*(9):600-602.

NIOSH (National Institute for Occupational Safety and Health) [2003]. NIOSH manual of analytical methods (NMAM®). 4th ed. Schlecht PC, O'Connor PF, eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 94–113 (August 1994); 1st Supplement Publication 96–135, 2nd Supplement Publication 98–119; 3rd Supplement 2003–154. Available at: http://www.cdc.gov/niosh/docs/2003-154/. Date accessed: November 2017.

NIOSH [2004]. NIOSH respirator selection logic. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health DHHS (NIOSH) Publication No. 2005-100. Available at: https://www.cdc.gov/niosh/docs/2005-100/pdfs/2005-100.pdf. Date accessed: October 2017.

NIOSH [2010]. NIOSH pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2010-168c. Available at: http://www.cdc.gov/niosh/npg/. Date accessed: November 2017.

NIOSH [2012]. Flavoring-related lung disease. Information for healthcare providers. Department of Health and Human Services, Centers for Disease Control and Prevention, DHHS (NIOSH) Publication No. 2012-148 (supersedes 2012-107). Available at: http://www.cdc.gov/niosh/docs/2012-148/. Date accessed: November 2017.

NIOSH [2016]. Criteria for a recommended standard: occupational exposure to diacetyl and 2,3-pentanedione. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2016-111. Available at: https://www.cdc.gov/niosh/docs/2016-111/. Date accessed: November 2017.

Nishimura F, Abe S, Fukunaga T [2003]. Carbon monoxide poisoning from industrial coffee extraction. JAMA *290*(3):334.

Ohashi Y, Motojima S, Fukuda T, Makino S [1992]. Airway hyperresponsiveness, increased intracellular spaces of bronchial epithelium, and increased infiltration of eosinophils and lymphocytes in bronchial mucosa in asthma. Am Rev Respir Dis *145*(6):1469-1476.
Oldenburg M, Bittner C, Baur X [2009]. Health risks due to coffee dust. Chest *136*(2):536-544

Oppenheimer BW, Goldring RM, Herberg ME, Hofer IS, Reyfman PA, Liautaud S, Rom WN, Reibman J, Berger KI [2007]. Distal airway function in symptomatic subjects with normal spirometry following World Trade Center dust exposure. Chest *132*(4):1275–1282.

OSHA (Occupational Safety and Health Administration) [1993]. Compliance and enforcement activities affected by the PELs decision. August 5, 1993 Memorandum. Availale at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=21220. Date accessed: November 2017.

OSHA [2003]. Enforcement policy for respiratory hazards not covered by OSHA permissible exposure limits. January 24, 2003 Memorandum. Available at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=24749. Date accessed: November 2017.

OSHA [2008]. Sampling and analytical methods: Method 1013 – Acetoin and diacetyl. Available at: http://www.osha.gov/dts/sltc/methods/validated/1013/1013.html. Date accessed: November 2017.

OSHA [2010]. Sampling and analytical methods: Method 1016 – 2,3-pentanedione. Available at: http://www.osha.gov/dts/sltc/methods/validated/1016/1016.html. Date accessed: November 2017.

OSHA [2014]. OSHA fact Sheet: Do you have work-related asthma? A guide for you and your doctor. Washington, D.C.: U.S. Department of Labor, Occupational Safety and Health Administration. Available at: https://www.osha.gov/Publications/OSHA3707.pdf. Date accessed: November 2017.

OSHA [2017]. Permissible exposure limits – annotated tables. Available at: https://www.osha.gov/dsg/annotated-pels/index.html. Date accessed: November 2017.

Park JH, Yoon JW, Shin YH, Jee HM, Wee YS, Chang SJ, Sim JH, Yum HY, Han MY [2011]. Reference values for respiratory system impedence using impulse oscillometry in healthy preschool children. Korean J Pediatr *54*(2)64-68.

Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, Coates A, van der Grinten CP, Gustafsson P, Hankinson J, Jensen R, Johnson DC, MacIntyre N, McKay R, Miller MR, Navajas D, Pedersen OF, Wanger J [2005]. Interpretative strategies for lung function tests. Eur Respir J *26*(5):948–968.

Perez T, Chanez P, Dusser D, Devillier P [2013]. Small airway impairment in moderate to severe asthmatics without significant proximal airway obstruction. Respir Med *107*(11):1667-1674.

Raffel JB, Thompson J [2013]. Carbon monoxide from domestic coffee roasting: a case report. Ann Intern Med *159*(11):795-796.

Rondón C, Campo P, Galindo L, Blanca-López N, Cassinello MS, Rodriguez-Bada JL, Torres MJ, Blanca M [2012]. Prevalence and clinical relevance of local allergic rhinitis. Allergy *67*(10):1282-1288.

Rondón C, Bogas G, Barrionuevo E, Blanca M, Torres MJ, Campo P [2017]. Nonallergic rhinitis and lower airway disease. Allergy *72*(1):24-34.

Rose JJ, Wang L, Xu Q, McTiernan CF, Shiva S, Tejero J, Gladwin MT [2017]. Carbon Monoxide Poisoning: Pathogenesis, Management, and Future Directions of Therapy. Am J Respir Crit Care Med *195*(5):596-606.

Sahay S, Gera K, Bhargava SK, Shah A [2016]. Occurrence and impact of sinusitis in patients with asthma and/or allergic rhinitis. J Asthma *53*(6):635-643.

Sakwari G, Mamuya SH, Bråtveit M, Moen BE [2013]. Respiratory symptoms, exhaled nitric oxide, and lung function among workers in Tanzanian coffee factories. J Occup Environ Med *55*(5):544-551.

Schulz H, Flexeder C, Behr J, Heier M, Holle R, Huber RM, Jörres RA, Nowak D, Peters A, Wichmann HE, Heinrich J, Karrasch S; KORA Study Group [2013]. Reference values of impulse oscillometric lung function indices in adults of advanced age. PLoS One *8*(5):e63366. doi: 10.1371/journal.pone.0063366.

Schulze J, Biedebach S, Christmann M, Herrmann E, Voss S, Zielen S [2016]. Impulse oscillometry as a predictor of asthma exacerbations in young children. Respiration *91*(2):107-114.

Shaaban R, Zureik M, Soussan D, Neukirch C, Heinrich J, Sunyer J, Wjst M, Cerveri I, Pin I, Bousquet J, Jarvis D, Burney PG, Neukirch F, Leynaert B [2008]. Rhinitis and onset of asthma: a longitudinal population-based study. Lancet *372*(9643):1049-1057.

Shi Y, Aledia AS, Tatavoosian AV, Vijayalakshmi S, Galant SP, George SC [2012]. Relating small airways to asthma control by using impulse oscillometry in children. Allergy Clin Immunol *129*(3):671-678.

Smith HJ, Reinhold P, Goldman MD [2005]. Forced oscillation technique and impulse oscillometry. In: Gosselink R, Stam H, eds. European Respiratory Monograph 31: Lung Function Testing. Vol. 10. Wakefield, UK: European Respiratory Society Journals, pp. 72–105.

Smith HJ (Hans-Juergen.Smith@CareFusion.com) [2015]. Questions about impulse oscillometry. Email of December 9, 2015, from Hans-Juergen Smith, CareFusion, to Rachel Bailey (feu2@cdc.gov), Respiratory Health Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Department of Health and Human Services.

Song TW, Kim KW, Kim ES, Park JW, Sohn MH, Kim KE [2008]. Utility of impulse oscillometry in young children with asthma. Pediatr Allergy Immunol *19*(8):763-768.
Tarlo SM, Lemiere C [2014]. Occupational asthma. N Engl J Med *370*:640-649.

Tarlo SM [2016]. Update on work-exacerbated asthma. Int J Occup Med Environ Health *29*(3):369-374.

Thomas KE, Trigg CJ, Baxter PJ, Topping M, Lacey J, Crook B, Whitehead P, Bennett JB, Davies RJ [1991]. Factors relating to the development of respiratory symptoms in coffee process workers. Br J Ind Med *48*(5):314–322.

Usmani OS, Singh D, Spinola M, Bizzi A, Barnes PJ [2016].The prevalence of small airways disease in adult asthma: A systematic literature review. Respir Med *116*:19-27.

Vogel J, Smidt U [1994] Impulse oscillometry. Analysis of lung mechanics in general practice and clinic, epidemiological and experimental research. 1st ed. Frankfurt: PMI-Verlagsgruppe.

Weinstein DJ, Hull JE, Ritchie BL, Hayes JA, Morris MJ [2016]. Exercise-associated excessive dynamic airway collapse in military personnel. Ann Am Thorac Soc *13*(9):1476-1482.

Zuskin E, Valić F, Skurić Z [1979]. Respiratory function in coffee workers. Br J Ind Med *36*(2):117–122.

Zuskin E, Kanceljak B, Skurić Z, Butković D [1985]. Bronchial reactivity in green coffee exposure. Br J Ind Med *42*(6):415-420.

Zuskin E, Schachter EN, Kanceljak B, Witek TJ Jr, Fein E [1993]. Organic dust disease of airways. Int Arch Occup Environ Health *65*(2):135-140.

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Availability of Report

Copies of this report have been sent to the employer, employees, and union at the facility. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

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