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

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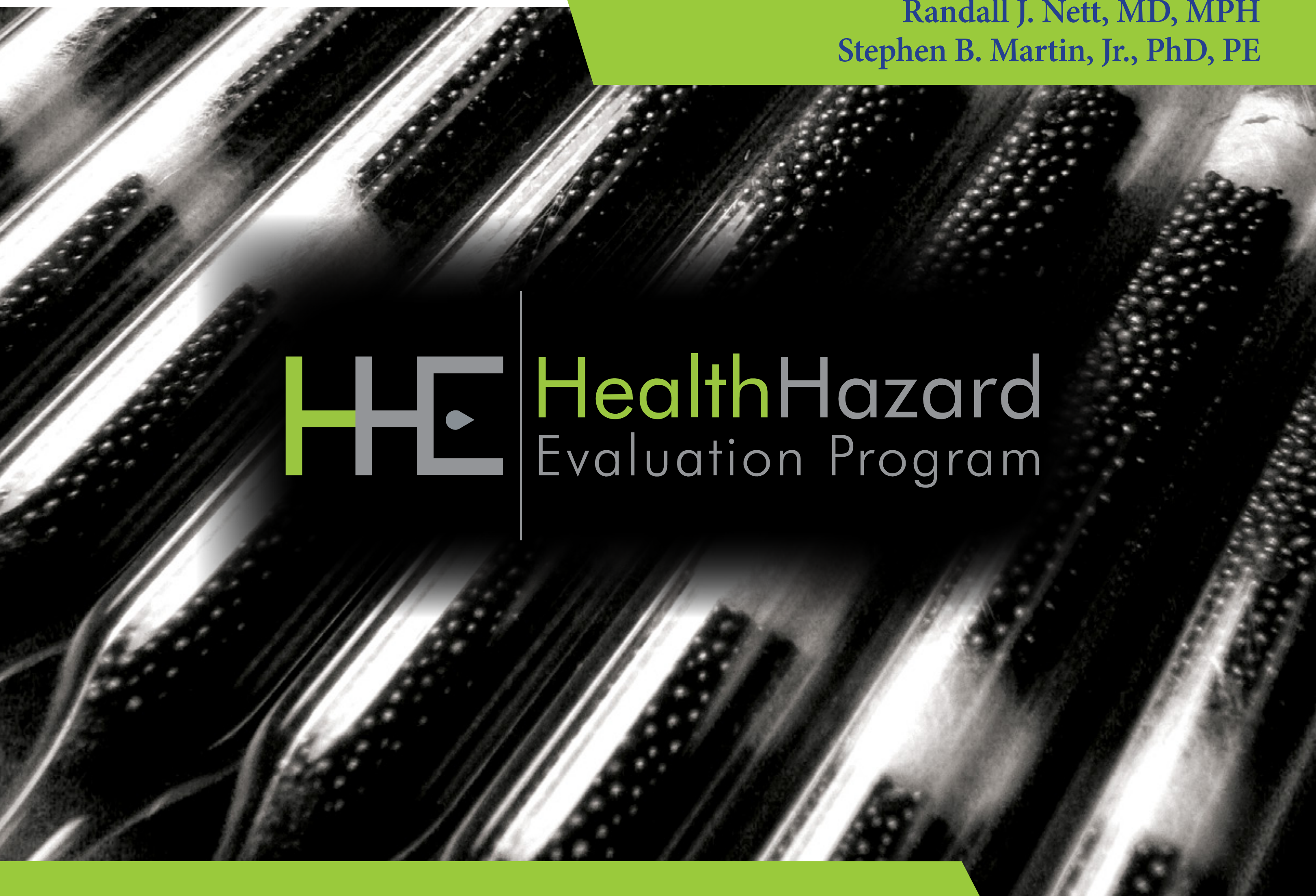

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Contents

The employer is required to post a copy of this report for 30 days at or near the workplace(s) of affected employees. The employer must take steps to ensure that the posted report is not altered, defaced, or covered by other material.

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 management at a coffee roasting and packaging facility. The request included concerns about the potential health effects from exposure to diacetyl during coffee roasting, grinding, and packaging.

What We Did

- We visited the coffee roasting and packaging facility in February and March 2017.
- We performed an industrial hygiene survey at the facility in February 2017.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of alpha-diketones. Specifically, we collected diacetyl, 2,3-pentanedione, and 2,3-hexanedione measurements on each day of our visit.
- We collected roasted coffee beans to measure their emission potential for diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We measured real-time air levels of carbon monoxide and carbon dioxide.
- We assessed the ventilation system at the facility.
- We administered a health questionnaire to employees and performed breathing tests.

What We Found

- On full-shift sampling, one production employee was exposed to diacetyl concentrations above the National Institute for Occupational Safety and Health recommended exposure limit of 5 parts per billion. The highest concentration of diacetyl we measured as an average across a full-shift was 5.6 parts per billion.
- Levels of diacetyl and 2,3-pentanedione in the air during short-term sampling were higher for tasks involving grinding roasted coffee

We evaluated respiratory health among employees and measured alpha-diketones (diacetyl, 2,3-pentanedione, and 2,3-hexanedione), other volatile organic compounds, carbon monoxide, and carbon dioxide in the air at a coffee roasting and packaging facility. One employee in the production area of the facility had one full-shift exposure that exceeded the NIOSH recommended exposure limit for diacetyl. One of the 15-minute short-term exposure samples collected on employees grinding roasted coffee beans exceeded the NIOSH recommended short-term exposure limit for diacetyl. Air levels of carbon monoxide exceeded the NIOSH ceiling limit of 200 parts per million in the area near the main grinders. Nose and sinus symptoms were the most commonly reported symptoms. Some employees reported their symptoms were better away from work. One of five participants had abnormal spirometry. We recommend engineering controls to mitigate exposure to diacetyl, 2,3-pentanedione, and carbon monoxide near the main grinders. We also recommend implementing administrative controls such as modification of work practices, training employees about workplace hazards, and instituting a medical monitoring program.

(maximum 31.7 parts per billion).

- One of the three 15-minute samples collected on employees performing grinding of coffee beans exceeded the National Institute for Occupational Safety and Health recommended short-term exposure limit for diacetyl of 25 parts per billion.
- Carbon monoxide levels exceeded the National Institute for Occupational Safety and Health recommended ceiling limit of 200 parts per million in the area near the grinders.
- All bulk samples of roasted coffee beans emitted diacetyl and 2,3-pentanedione.
- Nose and sinus symptoms were the most commonly reported symptoms. Some employees reported their symptoms were better away from work.
- One of five participants had abnormal spirometry.
- One of five participants 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.
- Consult with a ventilation engineer to develop an overall engineering control plan to reduce airborne alpha-diketone concentrations. Verify that adequate fresh, outdoor air is being supplied by the existing rooftop AHU, and, if not, increase the amount of outdoor air consistently provided to the production space during periods of occupancy.
- Install a local exhaust ventilation system at the main grinders to capture diacetyl, 2,3-pentanedione, and carbon monoxide emissions from the main grinders and packaging of ground coffee.
- Continue to cover bins of roasted beans to reduce emissions of alpha-diketones, carbon monoxide, and carbon dioxide into the air.
- Automate transfer of roasted beans, whenever possible, to minimize manual handling of roasted coffee beans.
- Conduct follow-up air sampling to verify that the modifications have been effective in reducing exposures to below the recommended exposure limits.
- Install a carbon monoxide monitor near the main grinders to alert employees if carbon monoxide levels exceed the National Institute for Occupational Safety and Health recommended ceiling limit of 200 parts per million.
- Continue to make N95 disposable filtering-face piece respirators available for voluntary use for protection against coffee dust exposure, such as when emptying burlap bags of green beans into the storage silos, cleaning the chaff out of the roaster exhaust system, emptying the chaff containers, or cleaning the green bean storage area.
- Encourage employees to report new, worsening, or ongoing 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

- Use any local exhaust ventilation as instructed by your employer when it is installed.
- As much as possible, avoid placing your head directly above or inside roasted bean storage bins.
- Some employees may wish to use N-95 disposable filtering-facepiece respirators for some tasks, such as when emptying burlap bags of green beans into storage containers, cleaning the chaff out of the roaster exhaust system, emptying the chaff containers, or cleaning the green bean storage area.
- Participate in any personal air sampling offered by your employer.
- Report new, persistent, or worsening respiratory symptoms to your personal healthcare provider and a designated individual at your workplace.
- Participate in your employer's medical monitoring program as instructed by your employer.

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Abbreviations

µg	Microgram
°F	degrees Fahrenheit
ACGIH®	American Conference of Governmental Industrial Hygienists
AHU	Air-handling unit
APF	Assigned protection factor
AX	Area of reactance
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	Forced expiratory volume in 1 second
Fres	Resonant frequency
FVC	Forced vital capacity
IDLH	Immediately dangerous to life or health
IOS	Impulse oscillometry
kPa/(L/s)	Kilopascals per liter per second
LOD	Limit of detection
LOQ	Limit of quantitation
LPM	Liters per minute
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
R5	Resistance at 5 Hertz
R20	Resistance at 20 Hertz
REL	Recommended exposure limit
STEL	Short-term exposure limit
TLV®	Threshold limit value
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 (NIOSH) received a request from management at a coffee roasting and packaging facility regarding concerns about health issues related to exposure to diacetyl during coffee roasting, grinding, and packaging. During February 27–March 2, 2017, we conducted an industrial hygiene survey, ventilation assessment, and medical survey at the facility. The industrial hygiene survey consisted of the collection of air samples and bulk samples of coffee for the analysis of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. Continuous monitoring instruments were used to monitor total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. The medical survey consisted of a health questionnaire and breathing tests.

One of the three personal full-shift air samples exceeded the NIOSH recommended exposure limit for diacetyl of 5 parts per billion. The personal air sample that exceeded the recommended exposure limit for diacetyl was collected on an employee with primary job duties on the production floor. None of the personal full-shift air samples exceeded the NIOSH recommended exposure limit for 2,3-pentanedione. The highest partial-shift and task-based diacetyl and 2,3-pentanedione exposure measurements were observed on employees that ground coffee, or worked in the packaging area near the grinders. Areas with ground coffee present, specifically the two main grinders, had the highest levels of diacetyl, 2,3-pentanedione, total volatile organic compounds, and carbon monoxide. We observed high instantaneous levels of carbon monoxide during grinding. Carbon monoxide levels measured on employees that ground coffee exceeded the NIOSH ceiling limit of 200 parts per million. Carbon dioxide levels were low throughout most of the facility.

Nose and sinus symptoms were the most commonly reported symptoms. Some employees reported their symptoms were better when away from work. One of the five participants had abnormal spirometry. We recommend a combination of engineering and administrative controls to minimize employee exposures. We also recommend a medical monitoring program to identify any employees who might 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 Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health (NIOSH) received a request from management at a coffee roasting and packaging facility. The request stated concerns about possible health issues related to exposure to diacetyl during coffee roasting and packaging. During February 27–March 2, 2017, we visited the facility to learn more about coffee processing and to conduct industrial hygiene and medical surveys. We collected area and personal breathing zone air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We also monitored and recorded carbon monoxide (CO), carbon dioxide (CO_2), and total volatile organic compounds (VOCs).

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. The 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 moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). Workers exposed for less time or at lower concentrations 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. CO and CO_2 are also produced as a result of reactions that take place during coffee roasting and are released during and after roasting and grinding by 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.

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 2016]. OSHA short-term exposure limits (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) 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 threshold limit values (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]. NIOSH also provides recommended 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 recommended 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. Exposure limits for compounds sampled during the NIOSH survey, February 2017.

Compound	OSHA*	ACGIH		NIOSH		
	PEL	TLV	STEL	REL	STEL	IDLH
Diacetyl	-	10 ppb	20 ppb	5 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; mg/m^3=milligram per cubic meter; 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 1200 ppm.
¶This is the NIOSH ceiling exposure limit for carbon monoxide. A ceiling concentration should not be exceeded at any time.

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 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]. Obliterative bronchiolitis has also been identified in employees at a coffee roasting and packaging 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 (range: 4.3 ppb to 166 ppb diacetyl; <5.2 ppb to 199 ppb 2,3-pentanedione) 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 for off-gassing, on a mezzanine above the grinding/packaging process [Duling et al. 2016]. At the time of the previous 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 roasting and packaging facilities that produce only unflavored coffee.

Work-related Asthma

Work-related asthma refers to asthma 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]. Work-related asthma includes asthma caused by sensitizers, which cause disease through immune (allergic) mechanisms, and asthma caused by 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 can 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

In March 2017, the coffee roasting and packaging facility had five full-time employees. The coffee company also had a café located off-site. At the coffee roasting and packaging facility, the production area was approximately 1,000 square feet. Roughly 280 pounds to 360 pounds of coffee were roasted and packaged per day, and approximately one-third of the coffee produced was ground coffee. The facility received green coffee beans in burlap bags. Green beans were stored in burlap bags and storage containers along the wall by the roasting and packaging area.

To prepare a batch for roasting, a roaster operator poured, weighed, and transferred the green coffee beans into the roaster. The roaster was a Probat roaster capable of roasting 26.4 pounds of coffee per batch. When ready, the roaster operator dropped the green beans into the roaster. The beans were heated to a specific temperature and for a specific time period for the desired roast. Time and temperature varied between different types of roasts. On average, roasts lasted 12 minutes to 15 minutes. Occasionally, the roaster operator would pull a small sample of beans from the roaster to check the color of the beans. At the end of each cycle, the roaster operator emptied the roasted beans into a cooling bin where they were agitated by a rotating arm. The cooling bin at the roaster utilized a downdraft exhaust system that pulled air downward past the roasted beans to accelerate cooling. The downdraft system exhausted through the roaster and then to the outside through a ventilation duct. The roaster operator monitored the roasting equipment throughout the roasting and cooling process. After cooling, the roasted beans were dispensed from the cooling bin of the roaster into transfer bins that were used by the roaster operator to transfer the roasted beans to the destoner. After being processed through the destoner, the beans were then ready for additional processing in the packaging area.

In the packaging area, orders were completed by weighing and packaging whole bean or ground coffee. All bags were manually weighed and packaged into compostable paper bags for bulk coffee or 12 oz bags equipped with one-way valves for off-gassing. For ground coffee, an employee weighed the whole beans before manually emptying the coffee beans into a grinder. Two grinders were used to grind coffee. One grinder could grind up to five pounds of coffee, and the other could grind up to three pounds of coffee. After packaging, bags of coffee were stored on open shelves and racks adjacent to the packaging area.

Every three months, the roasters were cleaned; accumulated chaff was removed and the exhaust lines from the roasters were cleaned.

Personal Protective Equipment
Employees wore gloves and hairnets while working in the coffee production area. Roasting employees who worked with green coffee beans voluntarily wore N95 filtering facepiece respirators.

Methods

We visited the coffee roasting and packaging facility during February 27–March 2, 2017. We held an opening meeting with management and an employee representative, collected air samples, performed a ventilation assessment, and conducted a medical survey. At the conclusion of our site visit, we held a closing meeting with management and employees.

We had the following objectives for the health hazard evaluation:

1. Measure employees' exposure to diacetyl, 2,3-pentanedione, and 2,3-hexanedione during coffee roasting and packaging;
2. Identify process areas or work tasks associated with emission of diacetyl, 2,3-pentanedione, and 2,3-hexanedione;
3. Measure levels of CO and CO_2 in different areas of the facility;
4. Assess the ventilation systems and the ventilation systems' effect on exposure levels;
5. Determine if employees had nose, eye, sinus, lower respiratory, and systemic symptoms and if those symptoms were work-related.
6. Determine if employees had abnormal lung function tests.

Industrial Hygiene Survey
Sampling Times for Alpha-Diketones
We designed the sampling strategy to assess full-shift exposures and identify tasks and processes that contributed 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 with the NIOSH RELs for diacetyl and 2,3-pentanedione. These average

concentrations might not tell us about short-term peak exposures that could be relevant to respiratory health, particularly for tasks 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.

Employees that participated in air sampling were given the opportunity to request their individual air sampling results.

Air Sampling and Analysis Using Modified Occupational Safety and Health (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 during our industrial hygiene survey. 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 time-weighted average (TWA) concentration from the two samples, assuming that the total 6-hour monitoring results reflected a full work shift (8-hour) TWA exposure. Although this might introduce some error, it is a conservative approach that is more protective of employees than the alternative assumption of no exposure during the last two hours of the shift. We refer to these samples as "full-shift samples" throughout this report. Some employees had shifts that lasted only two to three hours each day. For those employees, we refer to their time-weighted averages as partial-shift samples. 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 measure above background and is a criteria used to determine whether to report a result from a sample. 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 LODs were 0.01 micrograms per sample (µg/sample) for diacetyl, 2,3-pentanedione, and 2,3-hexanedione. These equate to 0.3 parts per billion (ppb) for diacetyl, 0.2 ppb for 2,3-pentanedione, and 0.2 ppb for 2,3-hexanedione for a typical full-shift TWA air sample but will vary depending on the volume of air collected during the sampling period. 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 LOQs equate to 1.1 ppb for diacetyl, 0.90 ppb for 2,3-pentanedione, and 0.79 ppb for 2,3-hexanedione for a typical full-shift air sample.

Air Sampling and Analysis Using Evacuated Canisters

We collected full-shift, time-weighted average area air samples and instantaneous task-based air samples for VOCs including diacetyl, 2,3-pentanedione, and 2,3-hexanedione using evacuated canisters. 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 control 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, and 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 0.78 ppb for diacetyl, 1.08 ppb for 2,3-pentanedione, and 1.92 ppb for 2,3-hexanedione based on a three-times dilution factor. 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 roasted coffees (whole bean and ground). For headspace analysis of alpha-diketones, we transferred 1 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 (Continuous) Air Sampling

We used RAE Systems (San Jose, CA) ppbRAE 3000 (Model #PGM-7340) monitors to measure concentrations of total VOCs 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 total VOCs. Areas where higher concentrations of total VOCs are measured help indicate areas where sampling to characterize specific exposures to alpha-diketones may be necessary. 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.

Ventilation Assessment

We took air flow measurements in the production space using a Model EBT731 Balometer Air Balancing Instrument (Alnor Products, TSI Incorporated, Shoreview, MN).We were unable to physically assess the single rooftop-mounted air-handling unit (AHU) during our visit, as there was no readily-available means to access the roof of the facility.

NIOSH Medical Survey

Participants

We invited all current employees to participate in the medical survey at the workplace during March 1–2, 2017. This facility also participated in a program in which adults with disabilities work for two hours per day. In this report, those employees will be referred to as 'day workers'. Because the work program is voluntary and day workers chose their work activity daily, different day workers can work at the facility each day. Because of the day workers' scheduling constraints, we could only invite four day workers to participate in the medical survey. Participation was voluntary and written informed consent was obtained from each participant before conducting the survey. 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 bronchodilator with repeat impulse oscillometry and spirometry. Day workers were excluded from analyses as they did not complete all medical testing. 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 roasting and packaging 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 [CDC 2018]. 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 the 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 4) 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 references 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 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.

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, 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 performed analyses using Excel (Microsoft®, Redmond, WA) and SAS version 9.3 (SAS Institute, Cary, NC). We calculated frequencies and compared prevalences of symptoms and diagnoses among participants. The small number of participants limited the conclusions that can be drawn from these analyses.

Results

All results tables are located in Appendix A.

Industrial Hygiene Survey

Personal and Area Full-shift Air Sampling Results
Personal and area full-shift air sampling results for diacetyl, 2,3-pentanedione, and 2,3-hexanedione using OSHA Method 1013/1016 can be seen in Table A1. On the days of our visit, only two employees worked for more than six-hours. One of the two employees worked more than six-hours on both days for a total of three full-shift sample measurements. We collected three personal and 25 area full-shift air samples. One personal air sample collected on an employee with primary job duties in the grinding and packaging area was above the NIOSH REL for diacetyl of 5 ppb, with a concentration of 5.6 ppb. No personal air samples were above the NIOSH REL for 2,3-pentanedione of 9.3 ppb. All personal and area samples were below the LOD for 2,3-hexanedione.

The area between the two grinders had the highest full-shift average area levels for diacetyl (18.5 ppb) and 2,3-pentanedione (9.0 ppb). One area full-shift air sample (collected in the area between the two grinders) was above the NIOSH REL for diacetyl. All other areas, including the area samples collected at the offsite café, were below the NIOSH REL for diacetyl and 2,3-pentanedione. Because area air samples are not personal air samples collected directly on an employee, the NIOSH RELs are not directly applicable to the results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the RELs can be used as points of reference.

Personal Partial-Shift Air Sampling Results

Personal air sampling results collected on employees who worked no more than three hours per shift can be seen in Table A2. We collected eight personal partial-shift samples using OSHA Method 1013/1016. Shift and sample duration lasted from 105 minutes to 180 minutes. Levels of diacetyl and 2,3-pentanedione were higher on employees performing duties in the grinding area, with a maximum diacetyl concentration of 8.3 ppb and maximum 2,3-pentanedione concentration of 5.2 ppb. We note that the NIOSH RELs for diacetyl and 2,3-pentanedione are provided as TWA concentrations over an 8-hour work shift during a 40-hour workweek. Because partial-shift samples were collected on employees who worked less than 20 hours a week and no more than four hours per day, they cannot be directly compared to the NIOSH RELs. All partial-shift samples were below the LOD for 2,3-hexanedione.

Task-Based Air Sampling Results

Personal task air concentration results can be seen in Table A3. We collected 19 personal task air samples using OSHA Method 1013/1016. Task sampling duration ranged from 13 minutes to 23 minutes, with a median of 15 minutes. We collected personal task air samples while employees roasted coffee (n = 11), ground coffee (n = 3), and packaged coffee (n = 5). The highest exposures to diacetyl (31.8 ppb) and 2,3-pentanedione (19.5 ppb) were measured while an employee was grinding coffee (Table A3). For task samples collected while employees packaged coffee, the highest exposures were 11.7 ppb diacetyl and 6.2 ppb 2,3-pentanedione. The highest exposures to diacetyl and 2,3-pentanedione while employees roasted coffee were 1.5 ppb and 0.9 ppb, respectively.

One of the three 15-minute samples collected while employees ground coffee exceeded the NIOSH STEL of 25 ppb for diacetyl (31.8 ppb). None of the 15-minute samples (n=3) exceeded the NIOSH STEL of 31 ppb for 2,3-pentanedione.

We collected 29 personal samples near the breathing zone of employees using instantaneous canisters (Table A4). Levels of diacetyl and 2,3-pentanedione observed in the breathing zone of employees using instantaneous canisters were lower than the levels described above. Instantaneous samples taken at the breathing zone of employees while they ground coffee were 2.6 ppb to 11.9 ppb for diacetyl, and 1.7 ppb to 6.1 ppb for 2,3-pentanedione. Breathing zone samples taken while an employee cleaned chaff out of the roaster exhaust lines ranged from 7.0 ppb to 12.1 ppb for diacetyl and 3.6 ppb to 6.4 ppb for 2,3-pentanedione. Instantaneous samples taken at the breathing zone while employees handled roasted beans ranged from less than 0.5 ppb to 7.2 ppb for diacetyl and less than 0.6 ppb to 4.1 ppb for 2,3-pentanedione. Samples collected while an employee dumped roasted beans from the roaster into the cooling bins ranged from 0.6 ppb to 1.1 ppb for diacetyl and less than 0.8 ppb to 1.0 ppb for 2,3-pentanedione.

Real-time Monitoring: Carbon Dioxide (CO_2), Carbon Monoxide (CO), and Total Volatile Organic Compounds (VOCs)
A summary of the real-time CO, CO_2, temperature, RH, and total VOC area monitoring results can be seen in Table A5. Levels of CO_2 and CO were consistent between the two days of our survey. Levels of CO_2 and CO measured at the roaster ranged from 433 ppm to 840 ppm for CO_2 and <0.1 ppm to 12.1 ppm for CO. Total VOC measurements at the roaster ranged from 0 ppb to 493 ppb, with an average of 193 ppb. Levels of CO_2 and CO measured at the grinder ranged from 430 ppm to 1,260 ppm for CO_2 and <0.1 ppm to 176.4 ppm for CO. Total VOC measurements at the grinders ranged from 0 ppb to 11,604 ppb. Levels of CO_2 and CO measured at the packaging weigh station ranged from 476 ppm to 1073 ppm for CO_2 and 0.5 ppm to 16.0 ppm for CO.

A summary of continuous, real-time, personal measurements of CO can be seen in Table A6. TWA personal CO measurements ranged from 0.2 ppm to 20.9 ppm and were below the NIOSH REL of 35 ppm for CO exposure. The highest CO levels were observed on production employees while they ground coffee. Levels of CO near an employee's breathing zone were as high as 301 ppm while an employee was grinding coffee; it exceeded the NIOSH recommended ceiling limit of 200 ppm for CO.

Ventilation Assessment
The production space (including the break room, production office, and storage area) was partitioned with partial walls and was served by a single air-handling unit mounted on the roof of the facility. Access to the roof was not readily available during our visit, so we were unable to visually inspect or document the make and model of the unit.

The AHU provided supply air flow to the production space through seven 2 feet × 2 feet supply vents in the ceiling of the production space. An eighth 2 feet × 2 feet supply vent was present in the ceiling of the production office. Three 2 feet × 2 feet ceiling mounted return grilles fed return air back to the AHU; one in the packaging area and two directly beside each other near the roaster. The AHU was supplying about 2,600 cubic feet per minute of supply air too the space, including the 200 cubic feet per minute supplied to the production office. Since we were unable to access the AHU, we could not verify whether any fresh, outdoor air was being supplied to the occupied space during our visit.

In addition to any potential fresh, outdoor air supplied by the rooftop AHU, there was a large passive makeup air opening in the west side of the production space, near the green bean storage area, that allowed fresh air into the space, when necessary. The amount of fresh air brought into the space through this opening is dependent on the outdoor weather conditions, other windows or doors being opened or closed, and, most importantly, the various operating modes of the roaster during a complete roasting cycle and each mode's individual air flow requirements.

Medical Survey

Demographics

Five (100%) full-time employees present during March 1–2, 2017, participated in the medical survey, including two café employees. Three (60%) participants were male, five (100%) were white, and the median age was 32 years (range: 27–36 years). Median tenure at the facility was 3.4 years (range: 1.6–5.1 years). Three (60%) participants were former smokers.

Four (80%) participants reported spending time in the production area of the facility during the work week. Of the four participants, all reported grinding coffee beans, moving roasted beans or ground coffee, and cleaning production machines. Three (75%) participants worked with green beans and worked where finished goods were stored. Two (50%) participants roasted coffee beans.

Three (60%) participants worked in the café and reported roasting and grinding coffee beans in the café. Two (67%) participants reported brewing coffee and using liquid flavorings.

Symptoms and Self-Reported Diagnoses

The prevalences of symptoms over both the last 12 months and four weeks reported at the time of the survey are listed in Table A7. Nose and sinus symptoms were the most commonly reported symptoms over the past 12 months (n=5, 100%) and four weeks (n=4, 80%). Two participants reported their sinus symptoms were better when away from work, and three participants reported their nose symptoms were aggravated at work.

Three (60%) participants reported one or more lower respiratory symptoms in the past 12 months: wheezing or whistling in chest, breathing trouble, or shortness of breath on level ground or walking up a slight hill. Two participants reported lower respiratory symptoms in the four weeks before the medical survey. Four (80%) participants reported at least one or more systemic symptoms in the last 12 months: flu-like achiness or achy joints, fever or chills, or unusual tiredness or fatigue. Three participants reported having one or more of these symptoms in the last four weeks.

Participants reported a history of nasal allergies (n=2), eczema (n=1), and asthma (n=1). One participant reported a nasal allergy diagnosis after being hired at the facility. The other diagnoses were made before hire. No participants reported a diagnosis of chronic bronchitis, bronchiolitis obliterans, interstitial lung disease, hypersensitivity pneumonitis, chemical pneumonitis, sarcoidosis, heart disease, or vocal cord dysfunction.

Medical Tests

One spirometry test was interpreted as having an obstructive pattern. One oscillometry test was interpreted as consistent with a large airways abnormality, and one was interpreted as consistent with a small and large airways abnormality. One exhaled nitric oxide test was interpreted as elevated.

Discussion

At the coffee roasting and packaging facility that is the subject of this report, the highest area samples for total VOCs, CO, diacetyl, and 2,3-pentanedione were observed in areas where coffee was ground between the two main grinders. Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other compounds such as CO_2 and CO are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for the 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].

Alpha-Diketones

Personal Air Sampling

One personal full-shift air sample taken inside the facility using standard OSHA methods was above the NIOSH REL for diacetyl. The highest personal full-shift diacetyl air sample (5.6 ppb) was collected on the production manager who had various duties in the production area. No personal air samples were above the NIOSH REL for 2,3-pentanedione. The highest partial-shift sample (8.2 ppb diacetyl and 5.2 ppb 2,3-pentanedione) was collected for 105 minutes on an employee with grinding duties. We note NIOSH RELs are intended to be directly compared with personal measurements that approximate an 8-hour TWA as part of a 40-hour workweek; therefore, the partial-shift samples that exceed a NIOSH REL are only an indication of potential personal exposures if that employee were to perform their job duties full-time.

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 5 ppb (a concentration slightly lower than the highest concentration measured at this facility), NIOSH estimated less than 1 in 1,000 workers would develop reduced lung function (FEV_1 below the 5th percentile). NIOSH predicted that around 1 in 10,000 workers exposed to diacetyl at 5 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]). After a 45-year working lifetime exposure to 10 ppb (a concentration higher than the highest concentration measured at this facility), NIOSH estimated that less than 2 in 1,000 workers would develop reduced lung function (FEV_1 below the 5th percentile). NIOSH predicted that 2 in 10,000 workers exposed to diacetyl at 10 ppb would develop more severe lung function reduction. The effects of a working lifetime exposure at 5.6 ppb is 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

One area sample collected in the area between the two main grinders had air levels (18.5 ppb) that exceeded the NIOSH REL for diacetyl. Areas near the two main grinders had the highest diacetyl (18.5 ppb) and 2,3-pentanedione (9.0 ppb) air levels. All other areas, including the area samples collected at the offsite café, were below the NIOSH REL for diacetyl and 2,3-pentanedione. We note that NIOSH RELs are intended to be directly compared to personal measurements; therefore, an area air sample that exceeds a NIOSH REL is only an indication of potential personal exposures.

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 tasks are so sporadic in coffee processing, with some only lasting a few seconds or minutes, we used instantaneous evacuated canisters to sample tasks that were only a few seconds to minutes long and OSHA Methods 1013/1016 for longer duration tasks. 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. The highest exposures to diacetyl (31.8 ppb) and 2,3-pentanedione (19.5 ppb) were measured while an employee ground coffee (Table A2). One fifteen-minute sample collected while an employee ground coffee exceeded the NIOSH STEL of 25 ppb for diacetyl. No 15-minute samples exceeded the NIOSH STEL of 31 ppb for 2,3-pentanedione. The greater surface area for off-gassing that is produced during grinding could have resulted in the higher air concentrations [Akiyama et al. 2003].

Task-based air samples for roasting and packaging were lower. The highest exposures to diacetyl and 2,3-pentanedione while employees roasted coffee were 1.5 ppb and 0.9 ppb, respectively. Diacetyl and 2,3-pentanedione concentrations while employees packaged coffee were as high as 11.7 ppb and 6.2 ppb, respectively. All 15-minute samples collected while employees roasted or packaged coffee were below the NIOSH STEL for diacetyl and 2,3-pentanedione.

Overall, instantaneous breathing zone samples were low. The highest instantaneous sample for diacetyl (12.1 ppb), and 2,3-pentanedione (6.4 ppb) was collected in the breathing zone of an employee while s/he cleaned chaff out of the roaster exhaust lines. The second highest instantaneous sample for diacetyl (11.9 ppb) and 2,3-pentanedione (6.1 ppb) were collected near the breathing zone of an employee while they ground coffee. Instantaneous samples of diacetyl and 2,3-pentanedione taken while employees were handling roasted whole beans were lower. The highest breathing zone sample taken while an employee dumped roasted beans from the roaster into the cooling bin had a diacetyl concentration of 1.1 ppb and a 2,3-pentanedione concentration of 1.0 ppb. Instantaneous samples collected at the breathing zone of an employee while s/he scooped roasted whole beans onto the scale and then into a package ranged from 5.9 to 7.2 ppb for diacetyl and 3.3 ppb to 4.1 ppb for 2,3-pentanedione.

Real-time Sampling for CO, CO_2, and VOCs
Our real-time monitoring found that the highest overall levels of total CO, CO_2, and VOCs were observed at the grinders when they were in use. The average daily CO_2 concentrations observed at the main grinders were 566 ppm on day 1 and 483 ppm on day 2, with a maximum of 1260 ppm, and were below the NIOSH REL (5,000 ppm) and OSHA PEL (5,000 ppm). Lower emissions were observed at the packaging weigh station and roasters.

None of the personal TWA levels of CO exceeded the NIOSH REL (35 ppm) or OSHA PEL (50 ppm). However, we noted two peak exposures that exceeded the NIOSH ceiling limit for CO of 200 ppm while an employee ground coffee. The NIOSH ceiling limit should not be exceeded at any time.

Ventilation
Local exhaust ventilation
Local exhaust ventilation systems capture contaminants where they are generated and exhaust them before inhalation by employees occurs. Local exhaust ventilation systems generally consist of hoods or enclosures, duct work, or fans. Depending on the contaminant and whether air is recirculated, filters or other air cleaning technologies can be incorporated. When properly designed local exhaust ventilation systems are installed, overall workplace exposure levels can be reduced by removing contaminants at the source. Higher concentrations of alpha-diketones were measured near the grinders. Local exhaust ventilation installed near the grinders can be used to reduce employee exposures during grinding tasks, as well as reduce overall alpha-diketone concentrations in the production space.

General exhaust or dilution ventilation
In an ideal environment, good general ventilation provides fresh air into the space and removes contaminated air. General exhaust ventilation allows contaminants to be emitted into the workplace and then dilutes the concentration of the contaminant to acceptable levels. This is generally done by providing fresh outdoor air (or recirculated, filtered air) to the space to provide dilution.

During the February 2017 survey, we were unable to determine if fresh, outdoor air was supplied to the production space by the rooftop AHU. However, it was clear that outdoor air could enter the facility via inconsistent passive air transfer through the opening on the east wall. Passive air transfer is largely dependent on weather conditions and operating parameters of the roasters. An adequate supply of outdoor air, typically delivered through the heating, ventilation, and air-conditioning system, is necessary in any occupied spaces to dilute pollutants that are released by equipment, processes, products, and people. If the amount of outdoor air supplied to the space is low, increasing the outdoor air flow will provide more dilution and removal of airborne contaminants from the space. Consistently supplying the production space with appropriate outdoor air may not bring all personal exposures to diacetyl and 2,3-pentanedione below the NIOSH RELs, but it is a relatively easy engineering control to implement. The existing AHU is likely capable of providing adequate outdoor air flows, so only minor adjustments (if any) to the operating controls may be necessary. Providing more outdoor air flow will enhance dilution and removal of contaminants, but there will be additional energy costs associated with heating and cooling that outside air for much of the year. Those decisions should be made as part of an overall plan to improve engineering controls at the facility. A ventilation system expert can help meet all ventilation requirements in the production space and other areas of the building occupied by employees.

Additional air sampling should be conducted if there are changes in production processes, controls, or work practices that potentially change exposure conditions within the workplace.

Medical Survey

Overall, nose and sinus symptoms were the most commonly reported. Some employees reported their symptoms were aggravated by work. Coffee dust is an organic dust known to cause respiratory symptoms [Zuskin et al. 1993; Sakwari et al. 2013]. 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 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 diseases such as allergic rhinitis (hay fever, nasal allergies) and sinusitis are sometimes associated with lower respiratory symptoms and asthma and can 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. Three of the five participants reported lower respiratory symptoms, and all five reported upper respiratory symptoms. 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 recommendations section, one way to prevent symptoms related to green coffee dust might be to make N-95 disposable filtering-face piece respirators available for voluntary use when emptying burlap bags of green coffee beans into storage containers or cleaning the green bean storage area.

Three (60%) participants reported lower respiratory symptoms in the 12 months before the survey. Of these three employees, two reported the workplace aggravated their symptoms. Lower respiratory symptoms caused by diseases such as asthma often improve when away from exposures that trigger symptoms while symptoms caused by 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 that 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 are 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].

Two workers had abnormal impulse ocillometry results. One worker had a large airways abnormality and one had both a small and large airways abnormality. 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 accesses 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 Assumpcão 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].

The respiratory symptoms reported and breathing test abnormalities identified during the survey are not specific to a particular respiratory problem or disease. They could be related to workplace exposures or to other factors. Indeed, some 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 air sampling detected employee exposures to diacetyl that exceeded the NIOSH REL. All production employees and any employees that assist with production tasks (e.g., roasting, interacting with open storage bins/containers of roasted coffee, grinding, weighing, or packaging coffee) 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 2017].

Conclusions

We identified specific work tasks that resulted in air concentrations of diacetyl that exceeded the NIOSH REL and STEL for diacetyl. One of the 3 personal full-shift air samples was above the NIOSH REL for diacetyl of 5 ppb. The only full-shift air sample above the NIOSH REL was collected on an employee with primary job duties on the production floor. High task-based diacetyl exposure measurements were observed on employees that ground coffee. Areas with ground coffee present, specifically between the two main grinders, consistently had the highest levels of diacetyl, 2,3-pentanedione, total VOCs, and CO. CO_2 levels were low throughout most of the facility. However, CO levels measured on employees grinding coffee exceeded the NIOSH ceiling limit of 200 ppm.

We were unable to visually assess the rooftop AHU or measure the amount of fresh, outdoor air supplied to the space by the ventilation system. Although there is some passive air transfer through the opening in the east wall of the facility, if the amount of outdoor air supplied to the space is low, increasing the outdoor air flow will provide more dilution and removal of airborne contaminants from the space. Consistently supplying the production space with appropriate outdoor air may still not bring all personal exposures to diacetyl and 2,3-pentanedoine below the NIOSH RELs. Regardless, working with a ventilation engineer to optimize outdoor air delivery is a relatively inexpensive, easy place to start engineering control improvements, as the existing AHU is likely capable of providing more outdoor air flows with only minor adjustments. Additionally, installing a local exhaust ventilation system around the grinders to immediately remove alpha-diketones produced during that operation could further reduce overall concentrations of alpha-diketones in the production space.

Overall, nose and sinus symptoms were the most commonly reported symptoms over the last 12 months and four weeks. Some employees reported their symptoms were better away from work. These respiratory symptoms reported and breathing test abnormalities identified during the survey are not specific to a particular respiratory problem or disease and could be related to workplace exposures or to other factors. 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.

Recommendations

On the basis of our findings, we recommend the actions listed below. 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. We encourage this coffee processing facility to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan.

Engineering Controls

Engineering controls reduce employees' exposures by removing hazards 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. Consult with a ventilation engineer to develop an overall engineering control plan to reduce airborne alpha-diketone concentrations. Verify that adequate fresh, outdoor air is being supplied by the existing rooftop AHU, and, if not, increase the amount of outdoor air consistently provided to the production space during periods of occupancy.
2. Install local exhaust ventilation at the grinders to capture contaminants generated during grinding tasks, before they can spread throughout the rest of the production area.
3. After engineering controls have been installed at the main grinders, conduct personal air monitoring for diacetyl and 2,3-pentanedione on employees with primary duties in the production area using OSHA Sampling Method 1012 for diacetyl [OSHA 2008] and OSHA Sampling Method 1016 for 2,3-pentanedione [OSHA 2010]. Because air levels of VOCs like diacetyl and 2,3-pentanedione can fluctuate from day to day based on production schedules, we recommend personal air sampling for diacetyl and 2,3-pentanedione over multiple days.

Administrative Controls

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

1. Install a CO monitor and alarm near the main grinders that can alert employees if CO levels exceed the NIOSH ceiling of 200 ppm. Employees should evacuate and move to an area of fresh air until the CO level drops below 200 ppm.
2. Whenever possible, employees should avoid spending time in the immediate area where coffee is being ground and where ground coffee is being packaged.
3. Cover bins of roasted beans to aid in reducing the overall emission of alpha-diketones

and other chemicals (e.g., CO, CO_2) into the workplace.

4. To reduce exposures to VOCs (including alpha-diketones), CO, and CO_2, minimize production tasks that require employees to place their heads directly above or inside the roasted bean bins.
5. Continue to periodically clean the roaster's exhaust according to manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve the efficiency, energy usage, and roaster performance.
6. 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.
7. 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 needed. Supporting programs such as training, change-out schedules, and medical assessment might 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 follow-up air sampling after engineering controls have been installed indicates levels of diacetyl and 2,3-pentanedione above their respective NIOSH RELs and STELs, we recommend respiratory protection be used during tasks with elevated exposures. To reduce exposures to alpha-diketones, NIOSH-certified respirators should be fitted with organic vapor cartridges. 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. Continue to make N95 disposable filtering-face piece respirators available for voluntary use for protection against green or roasted coffee 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. 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.

According to the NIOSH Criteria document [NIOSH 2016], employees should have baseline evaluations before they are allowed to work in or enter areas where they might be exposed to diacetyl, 2,3-pentanedione, or similar flavoring compounds. Air sampling results indicated that employees in the production area that roasted coffee, ground coffee, or weighed and packaged roasted coffee could be exposed to diacetyl above the NIOSH REL or STEL.

1. Institute a medical monitoring program for employees who work or assist in the production area. 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 a breakdown in exposure controls and potential risk for co-workers exists. 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 2017].

Appendix A: Tables

Table A1. Time-weighted average OSHA Method 1013/1016 personal and area full-shift air sampling results by location, NIOSH survey, February 2017

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Production Area	1	1 (100%)	5.6	5.6	1
Diacetyl	Personal	Roasting	2	2 (100%)	0.7	2.4	0
Diacetyl	Area	Café	5	5 (100%)	0.5	1.0	N/A
Diacetyl	Area	Outside	2	0 (0%)	<0.3	<0.4	N/A
Diacetyl	Area	Production Area	12	10 (83%)	<0.3	18.5	N/A
Diacetyl	Area	Production Office	2	2 (100%)	0.4	1.8	N/A
Diacetyl	Area	Roasting	4	4 (100%)	0.5	2.9	N/A
2,3-Pentanedione	Personal	Production Area	1	1 (100%)	3.3	3.3	0
2,3-Pentanedione	Personal	Roasting	2	2 (100%)	0.6	1.4	0
2,3-Pentanedione	Area	Café	5	5 (100%)	0.3	0.9	N/A
2,3-Pentanedione	Area	Outside	2	0 (0%)	<0.3	<0.3	N/A
2,3-Pentanedione	Area	Production Area	12	10 (83%)	<0.3	9.0	N/A
2,3-Pentanedione	Area	Production Office	2	2 (100%)	0.3	1.1	N/A
2,3-Pentanedione	Area	Roasting	4	3 (75%)	<0.3	1.7	N/A
2,3-Hexanedione	Personal	Production Area	1	0 (0%)	<0.2	<0.2	-
2,3-Hexanedione	Personal	Roasting	2	0 (0%)	<0.2	<0.3	-
2,3-Hexanedione	Area	Café	5	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Outside	2	0 (0%)	<0.2	<0.3	N/A
2,3-Hexanedione	Area	Production Area	12	0 (0%)	<0.2	<0.3	N/A
2,3-Hexanedione	Area	Production Office	2	0 (0%)	<0.2	<0.3	N/A
2,3-Hexanedione	Area	Roasting	4	0 (0%)	<0.2	<0.3	N/A

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD N (%)=number and percentage of samples above limit of detection (LOD); < indicates below the LOD; % Above REL=percentage 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 used for direct comparisons with area samples; "Production Area" location includes employees that were cross-trained and performed tasks at different areas; "–"indicates that there is currently no REL for 2,3-hexanedione.

Table A2. Time-weighted average OSHA Method 1013/1016 personal partial-shift air sampling results by location, NIOSH survey, February 2017

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (range) Sample Duration (minutes)
Diacetyl	Personal	Grinding	1	1 (100%)	8.2	8.2	105 (105–105)
Diacetyl	Personal	Packaging	6	6 (100%)	2.2	6.1	113 (106–120)
Diacetyl	Personal	Production Area	1	1 (100%)	1.4	1.4	180 (180–180)
2,3-Pentanedione	Personal	Grinding	1	1 (100%)	5.2	5.2	105 (105–105)
2,3-Pentanedione	Personal	Packaging	6	6 (100%)	1.1	4.4	113 (106–120)
2,3-Pentanedione	Personal	Production Area	1	1 (100%)	0.9	0.9	180 (180–180)
2,3-Hexanedione	Personal	Grinding	1	0 (0%)	<0.4	<0.4	105 (105–105)
2,3-Hexanedione	Personal	Packaging	6	0 (0%)	<0.4	<0.4	113 (106–120)
2,3-Hexanedione	Personal	Production Area	1	0 (0%)	<0.2	<0.2	180 (180–180)

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD N (%)=number and percentage of samples above limit of detection (LOD); < indicates below the LOD; ≤ indicates less than or equal to the LOD; % Above REL=percentage of samples above the NIOSH recommended exposure limit (REL); ppb=parts per billion; "Production Area" location includes cross-trained employees that performed tasks in different areas.

Table A3. Summary of OSHA Method 1013/1016 personal air sampling results by task, NIOSH survey, February 2017

Analyte	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (range) Sample Duration (minutes)
Diacetyl	Grinding coffee beans	3	3 (100%)	14.8	31.8	15 (15–15)
Diacetyl	Packaging coffee	5	5 (100%)	4.0	11.7	15 (15–15)
Diacetyl	Roasting coffee beans	11	1 (9%)	<0.6	1.5	16 (13–23)
2,3-Pentanedione	Grinding coffee beans	3	3 (100%)	7.7	19.5	15 (15–15)
2,3-Pentanedione	Packaging coffee	5	5 (100%)	2.9	6.2	15 (15–15)
2,3-Pentanedione	Roasting coffee beans	11	1 (9%)	<0.5	0.9	16 (13–23)
2,3-Hexanedione	Grinding coffee beans	3	0 (0%)	<0.7	<0.7	15 (15–15)
2,3-Hexanedione	Packaging coffee	5	0 (0%)	<0.7	<0.7	15 (15–15)
2,3-Hexanedione	Roasting coffee beans	11	0 (0%)	<0.5	<0.8	16 (13–23)

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD N (%)=number and percentage of samples above limit of detection (LOD); < indicates below the LOD; ≤ indicates less than or equal to the LOD; "All Over" includes cross-trained employees that performed tasks in different areas.

Table A4. Instantaneous evacuated canister method* air sampling results by task, NIOSH survey, February 2017

Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Grinding 5-pound bags of coffee	2.6	1.7	<1.2
Grinding 5-pound bags of coffee	7.6	4.1	<1.0
Grinding coffee	10.7	5.9	<1.3
Grinding coffee	8.1	4.4	<1.9
Grinding coffee	6.3	3.3	<1.3
Grinding coffee	6.9	3.8	<1.6
Grinding coffee	10.2	5.1	<1.7
Grinding coffee	11.9	6.1	<1.2
Cleaning chaff out of roaster exhaust lines	7.0	3.6	<2.0
Cleaning chaff out of roaster exhaust lines	12.1	6.4	<3.1
Cleaning chaff out of roaster exhaust lines	8.6	5.4	2.2
Dumping roasted beans from roaster into cooling bin	1.0	1.0	<1.2
Dumping roasted beans from roaster into cooling bin	0.6	<0.8	<1.4
Dumping roasted beans from roaster into cooling bin	1.1	1.0	<1.5
Dropping roasted beans from cooling bin into transfer container	0.9	<0.8	<1.4
Dropping roasted beans from cooling bin into transfer bin	0.5	<0.7	<1.2
Dropping roasted beans from cooling bin into transfer container	2.5	2.8	<1.4
Dropping roasted beans from cooling bin into transfer container	0.7	<0.7	<1.3
Dropping roasted beans from cooling bin into transfer container	0.8	<0.6	<1.1
Dropping roasted beans from cooling bin into transfer container	0.6	<0.6	<1.0
Dropping roasted beans from cooling bin into transfer container	<0.5	<0.6	<1.1
Dumping roasted beans from transfer container into destoner	0.6	<0.7	<1.2
Dumping roasted beans from transfer container into destoner	<0.6	<0.9	<1.6
Dumping roasted beans from transfer container into destoner	1.5	0.8	<1.1
Dumping roasted beans from transfer container into destoner	2.0	<1.5	<2.7
Quality control smelling tryer of beans	0.9	<1.1	<1.9
Scooping whole beans onto scale then into package	6.2	3.3	<1.0
Scooping whole beans onto scale then into package	7.2	4.1	<1.0
Scooping whole beans onto scale then into package	5.9	3.5	<1.0

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

***Sampling duration approximately 30 seconds; task-based air samples were collected by placing the inlet of the canister sampler in the employee's personal breathing zone as he/she performed work task to mimic exposure.**

Table A5. Summary of continuous area air monitoring results for mean concentrations of carbon dioxide, carbon monoxide, temperature, relative humidity, and total volatile organic compounds, NIOSH industrial hygiene survey, February 2017

Location	CO_2 (ppm)*	CO (ppm)*	Temperature (°F)*	Relative humidity (%)*	Total VOC (ppb)*
Roaster, day 1	553 (453–828)	2.3 (0–7.7)	–	–	193 (0–493)
Grinders, day 1	566 (456–1260)	3.4 (0–176.4)	–	–	497 (0–11,604)
Packaging weigh station, day 1	616 (531–1059)	3.1 (0.7–16.0)	72.4 (62.7–81.1)	28.6 (17.8–40.3)	–
Roaster, day 2	497 (433–840)	0.2 (0–12.1)	–	–	–
Grinders, day 2	483 (430–679)	0.2 (0-4.3)	–	–	172 (0–1052)
Packaging weigh station, day 2	587 (476–1073)	0.9 (0.5–6.8)	66.5 (62.0–71.6)	35.4 (27.1–41.6)	–

Note: NIOSH=National Institute for Occupational Safety and Health; CO_2=carbon dioxide; CO=carbon monoxide; ppm=parts per million; °F=degrees Fahrenheit; VOC=volatile organic compounds; "-"indicates the measurement was not recorded.
***Range can be seen in the parentheses.**

Table A6. Summary of continuous personal air measurements for carbon monoxide, NIOSH industrial hygiene survey, February 2017

Job Title	Work Area	CO (ppm)*
Roaster, day 1	Roaster	2.2 (0–11)
Roaster, day 2	Roaster	0.2 (0–4)
Production	Packaging	7.6 (3–13)
Production	Grinding	20.9 (4–301)
Production	Production and Administrative	3.8 (0–138)

Note: NIOSH=National Institute for Occupational Safety and Health; CO=carbon monoxide; ppm=parts per million.
***Mean concentrations of CO shown with range of measurements shown in the parentheses.**

Table A7. Prevalence of reported symptoms, NIOSH medical survey, March 2017

Symptom	Experienced in the last 12 months N = 5 Number (%)	Experienced in the last 4 weeks N = 5 Number (%)
Nose symptoms*	5 (100%)	4 (80%)
Eye symptoms†	4 (80%)	3 (60%)
Sinusitis or sinus problems	5 (100%)	4 (80%)
Problem with ability to smell	0 (0%)	–
Phlegm on most days for 3 months	0 (0%)	–
Lower respiratory symptoms (reported at least one of the following)	3 (60%)	2 (40%)
Chest wheezing or whistling	3 (60%)	2 (40%)
SOB on level ground or walking up a slight a hill	1 (20%)	–
Breathing trouble	1 (20%)	1 (20%)
Awoke with chest tightness	0 (0%)	0 (0%)
Awoke with shortness of breath	0 (0%)	0 (0%)
Usual cough‡	0 (0%)	0 (0%)
Asthma attack	0 (0%)	0 (0%)
Systemic symptoms (reported at least one of the following)	4 (80%)	3 (60%)
Flu-like achiness or achy joints	3 (60%)	1 (20%)
Fever or chills	3 (60%)	2 (40%)
Unusual tiredness or fatigue	1 (20%)	1 (20%)

Note: N=number of participants; SOB=shortness of breath; "-"=no four week question was 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?"

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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 available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2016-0005-3303.pdf.

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