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

Randy Boylstein, MS, REHS
Tia McClelland, MPH
Sandra White, MS

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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 the management of a coffee roasting and packaging facility. The request included concerns regarding exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting, storing, and grinding.

What We Did

- We visited the coffee roasting and packaging facility during January 30–February 2, 2017.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- 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 total volatile organic compounds, carbon monoxide, and carbon dioxide.
- We assessed the ventilation system at the facility.
- We administered a health questionnaire to employees and performed breathing tests.

We evaluated respiratory health and airborne exposures to alpha-diketones (diacetyl, 2,3-pentanedione, and 2,3-hexanedione), other volatile organic compounds, carbon monoxide, and carbon dioxide during coffee processing. All personal air samples collected using the standard method were above the National Institute for Occupational Safety and Health's recommended exposure limit of 5.0 parts per billion for diacetyl and 9.3 parts per billion for 2,3-pentanedione, with a maximum diacetyl concentration of 40.5 parts per billion and a maximum concentration of 2,3-pentanedione of 27.1 parts per billion. In addition, air sampling during short-term tasks identified several tasks (e.g., grinding roasted coffee beans, packaging coffee, cleaning the roaster, and roasting coffee beans) with higher exposures to alpha-diketones, including diacetyl, than other tasks. Eye, nose, and sinus symptoms were the most commonly reported symptoms. Wheezing was the most common lower respiratory symptom. One participant had abnormal spirometry. We recommend ventilation changes; training employees about workplace hazards; and the use of personal protective equipment if engineering and administrative controls do not keep exposures below the recommended levels. We also recommend instituting a medical monitoring program for employees who work in the production area.

What We Found

- All personal air samples collected using the standard method were above the National Institute for Occupational Safety and Health's recommended exposure limit of 5.0 parts per billion for diacetyl.
- The highest concentration of diacetyl measured with a full-shift personal air sample using the standard method (with tubes) was 40.5 parts per billion from a grinder/packager.
- The highest concentration of 2,3-pentanedione measured with a full-

shift personal air sample using the standard method (with tubes) was 27.1 parts per billion from a grinder/packager.

- Levels of diacetyl in the air were higher for tasks involving the grinding of roasted coffee beans, packaging coffee, cleaning the roaster, and roasting coffee beans.
- All four roasted coffee beans tested emitted 2,3-pentanedione; two of the four emitted diacetyl.
- Five personal samples from production employees exceeded the NIOSH ceiling limit of 200 parts per million for carbon monoxide. Samples ranged from 304 to 836 parts per million. Area indoor carbon monoxide levels ranged from 0.9 ppm–163.5 ppm.
- Upper respiratory symptoms and flu-like achiness were the most commonly reported symptoms. Some employees reported their upper respiratory symptoms were caused or aggravated by green coffee dust and ground coffee dust.
- Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom. Participants reported that these symptoms were not caused or aggravated by an exposure at work.
- One participant had abnormal spirometry.

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.
- Ensure adequate fresh, outdoor air is brought into all occupied spaces of the facility at all times, in accordance with American National Standards Institute /ASHRAE Standard 62.1-2016.
- Install general room ventilation in the production space and operate it continuously during the work-shift.
- Install local exhaust ventilation to reduce air concentrations of alpha-diketones during the following tasks: 1) grinding roasted coffee and 2) weighing and packaging roasted coffee.
- Avoid the use of compressed air as much as possible during cleaning. Instead, use a vacuum system with a high-efficiency particle air filter and wet methods whenever possible.
- Until exposures are controlled, provide respiratory protection to be used during tasks with elevated exposures, specifically during grinding weighing, and packaging roasted coffee.
- Continue to make N95 disposable filtering-face piece respirators available for voluntary use for protection against dust exposure.
- Evaluate the bakery further to identify sources of alpha-diketone exposure by

conducting personal air monitoring for diacetyl and 2,3-pentanedione.

- 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 installed.
- As much as possible, avoid placing your head directly above or inside roasted bean storage bins.
- Some employees might wish to use N95 disposable filtering-facepiece respirators when emptying burlap bags of green beans, cleaning the roaster, or cleaning the green bean storage area.
- Report new, persistent, or worsening respiratory symptoms to your personal healthcare provider(s) 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
ANSI	American National Standards Institute
AX	Area of reactance
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
COHb	Carboxyhemoglobin
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
FEV_1	1-second forced expiratory volume
Fres	Resonant frequency
FVC	Forced vital capacity
kPa/(L/s)	Kilopascals per liter per second
IDLH	Immediately dangerous to life or health
IOM	Institute of Occupational Medicine
LOD	Limit of detection
mL/min	Milliliter per minute
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppb	Parts per billion
ppm	Parts per million
QC	Quality control
R5	Resistance at 5 Hertz
R20	Resistance at 20 Hertz
REL	Recommended exposure limit
RH	Relative humidity
SMR	Standardized morbidity ratio
STEL	Short-term exposure limit
TLV®	Threshold limit value
TVOC	Total volatile organic compound
TWA	Time-weighted average

US	United States
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

The Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health received a request from the management of a coffee roasting and packaging facility. The request stated concerns regarding exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting and grinding. During January 31–February 1, 2017, we conducted an industrial hygiene survey at the facility. The industrial hygiene survey consisted of the collection of air samples for the analyses of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. Bulk samples were also collected for the analysis of diacetyl, 2,3-pentanedione, and 2,3-hexanedione emission potential. We used continuous monitoring instruments to measure total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. We also performed a ventilation assessment of the coffee production area. On February 2, 2017, we conducted a medical survey of production employees that consisted of a health questionnaire and breathing tests.

Overall, personal time-weighted average air concentrations of diacetyl and 2,3-pentanedione exceeded the National Institute for Occupational Safety and Health recommended exposure limits. 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. We identified jobs where some work tasks measured over minutes resulted in relatively higher air concentrations of diacetyl than other tasks. Specifically, grinding coffee beans, packaging coffee beans, and cleaning the roaster, were associated with diacetyl levels above the National Institute for Occupational Safety and Health recommended exposure limit. Overall, mucous membrane symptoms, specifically eye, nose, and sinus symptoms, and flu-like achiness or achy joints, were the most commonly reported symptoms. Some production employees reported their mucous membrane symptoms were caused or aggravated by green coffee dust, or ground coffee dust. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom. Participants reported that these lower respiratory symptoms were not work-related or aggravated by an exposure at work.One participant had abnormal spirometry. We recommend installing general room ventilation in the production space and operate it continuously during the work-shift and installing local exhaust in areas where higher exposure tasks were observed such as grinding, weighing and packaging roasted coffee. We also recommended implementing a medical monitoring program for employees who work in the production are 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 April 2016, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health (NIOSH) received a request from the management at a coffee roasting and packaging facility. The request stated concerns regarding potential employee exposure to diacetyl and 2,3-pentanedione during coffee processing. In January and February 2017, we conducted a ventilation assessment, an industrial hygiene survey, and a medical survey at the facility. We collected air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We monitored carbon monoxide (CO), carbon dioxide (CO_2), and total VOCs. After the visit, we provided the results of the survey in an interim report.

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

2,3-Hexanedione

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

Carbon Monoxide and Carbon Dioxide

CO and CO_2 are gases produced by combustion. They are also produced as a result of reactions that take place during coffee roasting. These gases are released during and after roasting and grinding by a process called off-gassing [Anderson et al. 2003; Hawley et al. 2017]. High exposures to CO and CO_2 can cause headache, dizziness, fatigue, nausea, altered mentation, 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 use 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) [Mandatory]

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 2018]. 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®) Threshold Limit Values (TLVs®) and NIOSH RELs.

American Conference of Governmental Industrial Hygienists (ACGIH) [Recommendations]

ACGIH is a professional, not-for-profit scientific association that reviews existing published, peer-reviewed scientific literature and publishes recommendations for levels of substances in air based on an 8-hour workday and 40-hour workweek. These recommendations are called TLVs [ACGIH 2018a]. 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 40hour 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 2018a]. 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 2018b].

National Institute for Occupational Safety and Health (NIOSH) [Recommendations]
NIOSH provides RELs as TWA concentrations that should not be exceeded over an 8- or 10-hour work shift, during a 40-hour workweek [NIOSH 2010]. RELs are intended to be protective over a 45-year working lifetime. NIOSH also provides STELs which are 15-minute TWA exposures that should not be exceeded at any time during a workday [NIOSH 2010]. Some chemicals have ceiling values, which are concentrations that should not be exceeded at any time [NIOSH 2010]. For some chemicals, NIOSH has established an Immediately Dangerous to Life or Health (IDLH) value. An IDLH value is a concentration of an air contaminant that can cause death or immediate or delayed permanent adverse health effects, or prevent escape from such an environment. Currently, NIOSH has RELs and STELs for diacetyl and 2,3-pentanedione. NIOSH does not have a REL or a STEL for 2,3-hexanedione. NIOSH does not have ceiling limits or IDLH values for diacetyl, 2,3-pentanedione, or 2,3-hexanedione.

For diacetyl and 2,3-pentanedione, the NIOSH RELs are 5.0 ppb and 9.3 ppb, respectively, as a TWA for up to an 8-hour workday during a 40-hour workweek (Table 1). The NIOSH STELs are 25 ppb for diacetyl and 31 ppb for 2,3-pentanedione [NIOSH 2016]. The NIOSH exposure limits do not differentiate between natural and synthetic chemical origin of diacetyl or 2,3-pentanedione. Although the NIOSH exposure limit for 2,3-pentanedione is above that of diacetyl, 2,3-pentanedione has been shown to be as hazardous as diacetyl [Hubbs et al. 2012; Morgan et al. 2012]. The 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. 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]. In addition to the REL, NIOSH also recommends an action level for diacetyl of 2.6 ppb to be used with exposure monitoring in an effort to ensure employee exposures are routinely below the diacetyl REL. When exposures exceed the action level, employers should take corrective action (i.e., determine the source of exposure, identify methods for controlling exposure) to ensure that exposures are maintained below the NIOSH REL for diacetyl [NIOSH 2016].

Table 1. Personal exposure limits for compounds sampled for during the NIOSH survey, January – February 2017.

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

Note: OSHA=Occupational Safety and Health Administration; ACGIH=American Conference of Governmental Industrial Hygienists; NIOSH=National Institute for Occupational Safety and Health; PEL=permissible exposure limit; STEL=short-term exposure limit; TLV=threshold limit value; REL=recommended exposure limit; IDLH=immediately dangerous to life or health; ppb=parts per billion; ppm=parts per million; "-"=no exposure limit available.

***There are no OSHA STELs for the compounds in the table.**

†The NIOSH RELs for diacetyl and 2,3-pentanedione are time-weighted averages for up to an 8- hour day, during a 40-hour workweek.

§OSHA and NIOSH limits are designed for occupational exposure measurements in manufacturing and other trades that have potential sources of carbon dioxide or carbon monoxide (e.g., coffee roasting, welding, vehicle exhaust, diesel engine exhaust). Typical levels of carbon monoxide in offices are 0–5 ppm. In office settings, carbon dioxide generally should not be greater than 700 ppm above outdoor carbon dioxide levels; this typically corresponds to indoor concentrations below 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 might include cough, shortness of breath on exertion, or wheeze, that do not typically improve away from work [NIOSH 2012]. Occupational obliterative bronchiolitis has been identified in flavoring manufacturing workers and microwave popcorn workers who worked with flavoring chemicals or butter flavorings [Kreiss 2013; Kim et al. 2010; Kanwal et al. 2006]. It has also been identified in employees at a coffee 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 elevated and identified three sources: 1) flavoring chemicals added to roasted coffee beans in the flavoring area; 2) grinding unflavored roasted coffee beans and packaging unflavored ground and whole bean roasted coffee in a distinct area of the facility, and 3) storing roasted coffee in hoppers, on a mezzanine above the grinding/packaging process, to off-gas [Duling et al. 2016]. At the time of the health hazard evaluation, workers had excess shortness of breath and obstruction on spirometry, both consistent with undiagnosed lung disease. Respiratory illness was associated with exposure and not limited to the flavoring areas [Bailey et al. 2015]. However, all workers who were diagnosed with obliterative bronchiolitis had worked in the flavoring area. To date, no cases of obliterative bronchiolitis have been reported in workers at coffee roasting and packaging facilities that produce only unflavored coffee.

Work-related Asthma

Work-related asthma refers to asthma that is brought on by ("occupational asthma") or made worse by ("work-exacerbated asthma" or "work-aggravated asthma") workplace exposures [Tarlo 2016; Tarlo and Lemiere 2014; OSHA 2014; Henneberger et al. 2011]. Work-related asthma includes asthma due to sensitizers, which cause disease through immune (allergic) mechanisms, and asthma due to irritants, which cause disease through non-immune mechanisms. Symptoms of work-related asthma include episodic shortness of breath, cough, wheeze, and chest tightness. The symptoms 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

This privately owned coffee roasting facility was located in a 2-story brick structure with a basement. The building was approximately 128 years old and 15,000 square feet. The facility featured a café, offices, production area, quality control (QC) lab, kitchen, storage area, and maintenance shop. The café and production area were located on the first floor. The offices and kitchen were on the second floor, and green coffee beans storage and maintenance shop were in the basement. At the time of the NIOSH visit in February 2017, there were approximately 50 employees at the location, with 10 working in production (5-day workweek, 8-hour shift). Approximately 1,000 pounds of coffee per day were produced (75% whole bean, 25% ground). No flavored coffee was produced. Forty employees did various administrative tasks including accounts receivable, customer service, inventory control, graphic design, sales, kitchen, and café operations.

Green Coffee Beans

Green coffee beans were delivered from suppliers in burlap or jute bags to the loading dock door. Upon arrival at the facility, bags of green beans were taken to the basement by hand and palletized for storage. When needed, bags were brought up to the first floor production area and placed near the roaster where employees opened the bags and weighed out batches.

Roasting

Roasting was conducted in a 132-pound maximum capacity roaster with typical roasts weighing 75 pounds to 100 pounds. To prepare a batch for roasting green coffee beans, an employee weighed green coffee beans and then placed them in a holding funnel at the top of the roaster. When ready, the coffee was charged into the roasting drum for 10 minutes to 15 minutes, depending on roast level. Upon completion, roasted coffee was dropped into a cooling tray directly beneath the roaster for 5 minutes to 10 minutes, and then was fed to the destoner/hopper. Then coffee was moved to 60-pound to 80-pound storage bins until bagged. Types of roasts included light, medium, and dark roasts. A roaster operator monitored the roasting equipment throughout the roasting and cooling process.

Chaff Cleaning Frequency

The chaff collector was located at the rear of the roaster and cleaned at the end of each day. The roaster had an afterburner; the after burner's filter was changed bi-weekly, and ductwork was removed and cleaned quarterly.

Off-gassing

Roasted coffee was stored in 60 pound to 80 pound bins for storage until needed for packaging. Coffee off-gassed for 24 hours to 48 hours before packaging.

Grinding

Grinding occurred daily, and the volume depended on orders. The facility had two 5-pound and one 66-pound capacity grinders. Approximately 50 to100 grinds were conducted per day with each grind lasting 15 seconds to 30 seconds in duration.

Packaging

Whole bean and ground coffee were hand packed at one of two worktables located in the production area or using a semi-automated fractional packager. Whole bean coffee was packaged in stand-up plastic zip pouches of various sizes, clear plastic bulk bags, and paper bags with a tin tie. Ground coffee was packaged in stand-up zip pouches in various sizes and fractional film bags. One-way valves were used on bags to allow for off-gassing.

Maintenance

There was a small maintenance area in the basement with five designated employees responsible for maintenance of production, kitchen, and café equipment.

QC Laboratory

The primary purpose of the QC laboratory, located across from the loading docks and staging area, was to ensure the quality of the coffee produced at the facility. The roaster operator conducted QC daily using a computerized system that produced roast curves. If the curve did not meet standards, coffee samples were taken to the QC laboratory for further analysis. Weekly QC, was conducted in the QC laboratory. Green coffee beans were roasted in a small roaster in the QC laboratory, then ground, and brewed followed by the cupping process where quality control staff smelled, tasted, and assigned scores to coffee brewed from samples of roasted beans. The roasted beans used for cupping came from three sources: green coffee bean samples from farmers (pre-ship), purchased green coffee beans shipped to the coffee roasting and packaging facility (arrival), and roasted coffee beans produced at the facility (production).

In addition to cupping, the quality control staff also graded green coffee beans, conducted triangulations to certify and grade tasters, and tested packaging.

Cleaning Activities
Employees routinely used brooms to sweep the production floor. They also used wet or dry wipes on tabletops and equipment surfaces and compressed air to remove coffee bean dust from surfaces and equipment.

Personal Protective Equipment
Employees were not required to wear a company uniform or protective clothing. N95 filtering facepiece respirators were available for voluntary use. We did not observe any employees wearing respirators.

Ventilation
The production area had no mechanical ventilation other than the exhaust through the roaster. Windows and doors were opened, and fans located in some widows operated in the warmer months. There was one environmental heater that operated during the colder months.

Methods

We visited the coffee facility during January 30–February 2, 2017. We conducted a walkthrough of the facility with management, collected bulk samples and air samples, performed a ventilation assessment, and conducted a medical survey of mainly production 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, and café activities;
2. Identify process areas or work tasks associated with emissions of diacetyl, 2,3-pentanedione, and 2,3-hexanedione;
3. Measure levels of CO and CO_2 throughout the facility;
4. Assess ventilation systems and their effect on exposure levels;
5. Determine if employees had mucous membrane, respiratory, or systemic symptoms and the proportion of those symptoms that were work-related or aggravated by work;
6. Determine if employees had abnormal lung function tests; and
7. Compare employees' prevalence of respiratory symptoms and healthcare provider-diagnosed asthma to expected levels based on general population values.

Industrial Hygiene Survey
Sampling Times for Alpha-Diketones
We designed the sampling strategy to assess full-shift exposures and to identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. Sampling was conducted over multiple days at the roasting and packaging facility and on a single day at the café. For diacetyl, 2,3-pentanedione, and 2,3-hexanedione, the air samples

were collected over seconds, minutes, and hours. Samples collected over minutes can help inform recommendations related to short term exposure limits (STELs) and those 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 when tasks are repeated multiple times per day. Therefore, during particular tasks, we collected personal air samples over several minutes; these samples can provide information about which tasks have relatively higher exposures. To help identify point sources of chemicals, we also performed real-time sampling and collected instantaneous samples over seconds.

Employees who 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 Administration (OSHA) Methods 1013/1016

We collected personal and area air samples for diacetyl, 2,3-pentanedione, and 2,3-hexanedione on silica gel sorbent tubes during the industrial hygiene survey over multiple days. The samples were collected and analyzed according to the modified OSHA sampling and analytical Methods 1013/1016 [OSHA 2008; OSHA 2010; LeBouf and Simmons 2017]. In accordance with the two methods, two glass silica gel sorbent tubes were connected by a piece of tubing and inserted into a protective, light-blocking cover. The tubes were connected in series to a sampling pump pulling air through the tubes at a flow rate of 50 milliliters per minute (mL/min). The sampling setup was attached to an employee's breathing zone or placed in an area basket in various places throughout the facility. For full-shift sampling, we collected two consecutive 3-hour samples and calculated the TWA concentration from the two samples, assuming that the total 6-hour monitoring results reflected a full work shift (8-hour) TWA exposure. 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. We also collected personal 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 from both visits were analyzed using an Agilent 7890/7001 gas chromatograph/mass spectrometer system operated in selected ion monitoring mode for increased sensitivity compared to the traditional flame ionization detector used in OSHA Methods 1013 and 1016 [LeBouf and Simmons 2017].

A limit of detection (LOD) is the lowest mass that an instrument can detect above background and is a criterion used to determine whether to report a result from a sample. The LODs were 0.010 micrograms per sample (μg/sample) for diacetyl, 0.01 μg/sample for 2,3-pentanedione, and 0.010 μg/sample for 2,3-hexanedione. For a typical full-shift TWA air sample, these equate to 0.32 ppb for diacetyl, 0.27 ppb for 2,3-pentanedione, and 0.24 ppb for 2,3-hexanedione. The LODs for task samples vary because of differing air volumes collected while sampling specific tasks and are higher than typical LOD values. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

Air Sampling and Analysis Using Evacuated Canisters

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

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system pursuant to a published method validation study [LeBouf et al. 2012], with the following modifications: the pre-concentrator was a Model 7200 (Entech Instruments, Inc., Simi Valley, CA), and six additional compounds, diacetyl, 2,3-pentanedione, 2,3-hexanedione, acetaldehyde, acetonitrile, and styrene, were included. At present, this canister method is partially validated [LeBouf et al. 2012] and not considered the standard method. For the visit, the LODs were 0.39 ppb for diacetyl, 0.55 ppb for 2,3-pentanedione, and 0.95 ppb for 2,3-hexanedione based on a three-times dilution factor, which is typical for restricted flow controller samplers. However, LODs are dependent on the pressure inside each canister after the samples have been collected, and they might 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 Air Sampling

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

Ventilation Assessment

We used smoked tube to assess airflow patterns at doors throughout the production areas. At the time of the survey, all doors were closed between the production area, outside, and other areas of the building.

NIOSH Medical Survey

Participants

We invited all current production employees to participate in the medical survey at the workplace on February 2, 2017. Participation was voluntary; written informed consent was obtained from each participant before testing. The survey included, in the order performed, a medical and work history questionnaire, quantification of exhaled nitric oxide, impulse oscillometry, and spirometry. We mailed participants their individual reports explaining their breathing test results and recommended each participant provide the information to their personal physician.

Questionnaire

We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee 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 three measurements or calculations: 1) forced vital capacity (FVC), (the total amount of air the participant can forcefully blow out after taking a deep breath), 2) FEV_1 (the amount of air that the participant can blow out in the first second of exhaling), and 3) the ratio of FEV_1 to FVC. We used American Thoracic Society criteria for acceptability and repeatability [Miller et al. 2005].

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

Impulse Oscillometry

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

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

Bronchodilator Reversibility Testing for Impulse Oscillometry and Spirometry

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

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

Statistical Analysis
Industrial Hygiene Survey and Ventilation Assessment
We performed analyses using Excel (Microsoft®, Redmond, WA) and SAS version 9.4 (SAS Institute, Cary, NC). We created summary statistics by work area location, job title, and task. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

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

Results

Industrial Hygiene Survey Results
Personal and Area Full-shift Air Sampling Results
<u>OSHA Methods 1013/1016</u>
Table A1 presents the personal and area full-shift air sampling results from our visit in January and February 2017. We collected 15 personal and 30 area full-shift air samples. All 15 personal air samples were above the NIOSH REL for diacetyl of 5.0 ppb and nine of 15 were above the NIOSH REL for 2,3-pentanedione of 9.3 ppb. A grinder/packager had the highest exposure to diacetyl (40.5 ppb) and 2,3-pentanedione (27.1 ppb). A roaster had the second highest exposure to diacetyl (34.7 ppb) and 2,3-pentanedione (25.1 ppb). Seven of the 15 personal air samples were above the LOD for 2,3-hexanedione. An employee working

in the production area had the highest exposure to 2,3-hexanedione (1.3 ppb). The second highest exposure of 1.2 ppb was captured in the roasting area.

Areas throughout the coffee roasting and packaging facility such as the bakery, café, administration, grinding, packaging, roasting, roasted bean storage, QC lab, warehouse and training center had air levels that exceeded the NIOSH REL for diacetyl. Twenty-three of 30 area samples for diacetyl and 14 of 30 area samples for 2,3-pentanedione exceeded the NIOSH REL. Packaging had the highest diacetyl (10.7 ppb–61.2 ppb) and 2,3-pentanedione (0.3 ppb–37.9 ppb) air levels. The roasting and roasted storage beans area had the second highest air concentrations for diacetyl (36.2 ppb and 41.3 ppb) and 2,3-pentanedione (29.3 ppb and 28.4 ppb). Eight out of 30 area air samples were above the LOD for 2,3-hexanedione. The packaging and roasting areas had the highest air levels of 2,3-hexanedione (1.4 ppb and 1.2 ppb). 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.

Short-Term Task-based Air Sampling Results

OSHA Methods 1013/1016

Table A2 presents the short-term personal task-based air concentrations for diacetyl, 2,3-pentanedione, and 2,3-hexanedione from our visit in January 2017–February 2017 by task. We collected 96 personal task-based air samples. The task of grinding coffee beans (13 minute task) had the highest exposure to diacetyl (66.9 ppb) and 2,3-pentanedione (53.8 ppb). The task of packaging coffee (15 minute task) had the second highest exposure to diacetyl (56.0 ppb) and 2,3-pentanedione (46.6 ppb). All samples were below the LOD for 2,3-hexanedione.

Evacuated Canisters

Instantaneous Task-based Air Sampling Results

Table A3 presents 19 source air samples that were collected during various tasks. Diacetyl concentrations ranged from 5.7 ppb–148 ppb; 2,3-pentanedione concentrations ranged from 6.6 ppb–94.7 ppb; 2,3-hexanedione concentrations ranged from <1.0 ppb–4.1 ppb. The highest concentrations for diacetyl, 2,3-pentanedione, and 2,3-hexanedione were captured during the manual mixing of ground coffee inside a metal container.

Instantaneous Source-based Air Sampling Results

Table A4 presents the 11 source air samples collected during the visit from the following locations: 1) five inches above whole dark decaf beans while being scooped into the grinder; 2) above bins in the middle of the off gas area; 3) at the mouth of a grinder nozzle into a barrel (decaf); 4) directly over a bag of five pound medium roast; 5) directly over the cooling bin of dark French roast; 6) directly above a bag mouth at first small grinder while grinding medium roast; 7) in a bin of dark roast that was roasted 24 hours prior and was ready to be mixed into a blended coffee, and 8) in a bin of light/medium roast that was roasted four hours prior. Diacetyl concentrations ranged from 31.7 ppb–9062 ppb; 2,3-pentanedione concentrations ranged from 18.9 ppb–6897 ppb; 2,3-hexanedione concentrations ranged from 1.7 ppb–270 ppb. The highest concentrations of diacetyl, 2,3-pentanedione, and

2,3-hexanedione were captured at the first small grinder directly above the mouth of the bag while ground medium roast coffee was falling into a bag (9062 ppb, 6897 ppb, 270 ppb).

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

Table A5 presents the results from real-time monitoring for CO, CO_2, temperature, and RH collected during the visit. Indoor CO levels ranged from 0.9 ppm–163.5 ppm. The highest CO level occurred in the grinding area. CO_2 levels within the facility ranged from 271 ppm–1280 ppm. The highest level of CO_2 was captured in the quality control lab. None of the CO or CO_2 levels collected were above exposure limits. Recorded temperatures ranged from 66.1–88.3°F during the survey. The highest temperatures (77.4–88.3°F) were captured near the roaster. Low levels of RH (13.2–32.3) were present during the sampling period, which could be attributed to seasonal conditions. During the visit, we also collected total VOCs in various locations throughout the facility including packaging, roasting, grinding, quality control lab/cupping room, and the bakery. The highest total VOCs were captured in the packaging, grinding, and roasting areas, and the QC lab; the highest exposure occurred in roasting.

Table A6 presents the results from the 11 real-time personal CO measurements collected on production employees, roasters, QC personnel, and a bakery employee during the visit. Elevated levels of CO were observed among four production employees; maximum levels ranged from 8 ppm–836 ppm. Elevated maximum levels of CO could be contributed to handling of freshly ground and whole bean coffee during tasks such as weighing and hand packing. In the production area, five personal samples (range: 304 ppm–836 ppm) exceeded the NIOSH ceiling limit of 200 ppm. The personal sample captured on a roaster (60 ppm) revealed low levels of CO, possibly because of the ventilation exhaust of the roaster.

Increased concentrations of TVOCs were identified around areas that roasted, ground, or packaged roasted coffee. Additionally, an increased concentration was found in the cupping room.

Bulk Samples and Headspace Results

Table A7 presents the bulk sample results using headspace analysis. Air concentrations of diacetyl ranged from below the limit of detection to 323 ppb for whole bean coffee. Air concentrations of 2,3-pentanedione ranged from 201 ppb to 500 ppb for whole bean coffee. The bulk samples for whole bean coffee were collected from the whole bean coffee storage bins. There was a 4 month storage time before bulk samples were analyzed, which may have affected the results.

Ventilation Assessment

The production area had no mechanical ventilation at the time of the survey. The only source of ventilation in the production area was an exhaust stack that served the roaster and the use of open windows and doors during the warmer months. Fans were also operated during the warmer months in some windows. Through the use of smoke tubes, the production area was found to be under negative pressure with respect to the outside and other areas of the building. In other words, air was being drawn into the production area and out the roaster exhaust stack.

Medical Survey Results

Demographics

Eight of 11 (73%) employees that performed coffee production tasks in either the production or quality control/training areas participated in the medical survey. The majority of participants were male (63%), and all were Caucasian, with a mean age of 31 years and average tenure at the company of 5.7 years. None of the participants were current smokers, although six (75%) reported a former smoking history.

All eight participants reported working or entering the production area, ranging from one hour to 40 hours a week, with an average of 25 hours per week. In addition, all had performed tasks or activities related to coffee processing in the production area. Most reported working with green beans (n=6) and/or grinding roasted beans (n=5).

Symptoms and Self-Reported Diagnoses

The prevalences of symptoms over the last year and last four weeks at the time of the survey are listed in Table A8. Nasal symptoms were the most commonly reported symptom (n=7, 88%), followed by eye and sinus symptoms (both: n=4, 50%). Less than half of the participants noted that their symptoms improved when away from work and/or were caused or aggravated by exposures at work, including dust and coffee grounds.

Wheeze was the most commonly reported lower respiratory symptom (n=2, 25%), followed by trouble with breathing (n=1, 13%). No participants reported that these lower respiratory symptoms were work-related or aggravated by an exposure at work.

Flu-like achiness or achy joints was the most commonly reported systemic symptom (n=4, 50%). One (13%) participant reported that this was aggravated at work and improved when away from work.

One participant reported a diagnosis of asthma prior to employment at the coffee roasting and packaging facility. One participant reported a diagnosis of hay fever.

Medical Tests

Two participants had possible breathing test abnormalities. One spirometry test was interpreted as having a possible airways obstruction. One impulse oscillometry test was interpreted as indicating a possible large airways abnormality. There were no participants with elevated nitric oxide levels.

NHANES Comparison of Symptoms and Diagnoses

The prevalence of selected symptoms (including wheeze and shortness of breath) and diagnoses (including asthma) among participants was not different than expected from comparisons to the general U.S. population.

Dicussion

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 production areas where coffee was packaged, ground, and roasted; in areas where roasted coffee was stored; and in the QC area during cupping activities. Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other chemicals such as CO and CO_2 are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for 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]. Occupational exposure to diacetyl and 2,3-pentanedione can cause loss of lung function and the lung disease obliterative bronchiolitis [NIOSH 2016].

Alpha-Diketones

Personal Full-shift Sampling

All full-shift personal (two bakers, five grinders/packagers, four production office staff, two quality control workers, and two roasters) air samples were above the NIOSH REL for diacetyl and 60% of full-shift personal air samples were above the NIOSH REL for 2,3-pentanedione. People who grind and package roasted coffee (40.5 ppb for diacetyl and 27.1 ppb for 2,3-pentanedione) had the highest exposures followed by employees who roast coffee (34.7 ppb for diacetyl and 25.1 ppb for 2,3-pentanedione). The observed full-shift exposure levels were influenced by peak exposures that occurred during roasting, grinding, and packaging coffee beans followed by periods of lower exposures. Alpha-diketone emissions of diacetyl and 2,3-pentanedione into the workplace air are directly related to the amount of roasted coffee being produced. The two personal (7.7 ppb and 8.5 ppb) air samples collected in the bakery area that exceeded the NIOSH REL for diacetyl were most likely caused by the use of butter and flavorings containing butter or diacetyl in the bakery. During the sampling, a table located in the bakery had recently been stacked with over 20 one-pound loaves of butter to be used in pastry making.

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 (Tables 5-27 and 5-34) [NIOSH 2016], after a 45-year working lifetime exposure to 20 ppb (a concentration lower than the highest concentration measured at this facility), NIOSH estimated about 5 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted 5 in 10,000 workers exposed to diacetyl at 20 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 50 ppb (a concentration higher than the highest concentration of 40.5 ppb measured at the facility), NIOSH estimated that about 12 in 1000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted about 12 in 10,000 workers exposed to diacetyl at 50 ppb would develop more severe lung function reduction. The effects of a working lifetime exposure at 40.5 ppb is closer to 50 ppb than 20 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 about 1 in 1000 workers. NIOSH recommends taking steps to reduce diacetyl exposures to below the REL of 5 ppb whenever possible.

Task-Based Exposures

Coffee processing involves multiple tasks that might 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). Because 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 lasted only a few seconds to minutes and OSHA Methods 1013/1016 for longer duration tasks. We sampled by task, with varying durations, to understand which tasks might 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. As noted earlier, four 15-minute personal air samples taken during grinding roasted coffee exceeded the STEL for diacetyl and 2,3-pentanedione. The maximum concentrations were 66.9 ppb for diacetyl and 53.8 ppb for 2,3-pentanedione. The greater surface area for off-gassing produced during grinding could have resulted in the higher air concentrations [Akiyama et al. 2003].

Carbon Monoxide

The grinding area had the highest level of CO (163.5 ppm). Five personal CO samples (range: 304 ppm–836 ppm) exceeded the NIOSH ceiling limit of 200 ppm. These levels could be contributed to handling freshly ground and whole bean coffee during tasks such as weighing and hand packaging.

Bulk Samples

Diacetyl is not found in green beans and forms later in the coffee roasting process [Daglia et al. 2007]. As expected, we found that roasted coffee emits alpha-diketones into the headspace of sealed vessels, indicating that roasted coffee is a source of alpha-diketones in the facility. Caution should be taken when interpreting these results because bulk samples collected during our visit were not analyzed immediately after sampling, and the samples had time to off-gas before performing the headspace analysis. We also do not know how long the beans were in the storage bins before collecting the samples, but generally the time between roasting and packaging is hours to days. The amount of time roasted beans had off-gassed could be responsible for differences in headspace analysis results.

Medical Survey

Overall, mucous membrane symptoms, specifically eye, nose, and sinus symptoms, were the most commonly reported symptoms. Some production employees reported their mucous membrane symptoms were caused or aggravated by green coffee dust or roasted coffee dust. Coffee dust is an organic dust known to cause respiratory symptoms [Zuskin et al.

1993; Sakwari et al. 2013]. Green and roasted coffee dust 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 can experience irritant-type symptoms from exposure to coffee dust [Oldenburg et al. 2009].

Upper respiratory disease such as allergic rhinitis (hay fever, nasal allergies) and sinusitis are sometimes associated with lower respiratory symptoms and asthma and might precede the diagnosis of asthma [Shaaban et al. 2008; EAACI Task Force on Occupational Rhinitis et al. 2008; Rondón et al. 2012, 2017; Sahay et al. 2016]. Upper respiratory involvement (e.g., rhinitis, sinusitis) can result in suboptimal control of asthma. All participants that reported lower respiratory symptoms also reported nasal or sinus problems. 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 and chaff might be to make N-95 disposable filtering facepiece respirators available for voluntary use when working with green beans and chaff.

The number of participants with physician-diagnosed asthma was not different from that observed in the U.S. population. Two participants (25%) reported one or more lower respiratory symptoms in the 12 months before the medical survey. Neither participant reported their lower respiratory symptoms were work-related. Asthma symptoms often improve when away from exposures that trigger symptoms while other lung diseases such as obliterative bronchiolitis or COPD generally do not improve. Spirometry can be used to help detect and follow individuals with asthma and other lung diseases such as obliterative bronchiolitis or COPD. Spirometry can show if air is exhaled from the lungs more slowly than normal (i.e. obstructive abnormality) or if the amount of air exhaled is smaller than normal (i.e., restrictive abnormality). In asthma, there is intermittent airways obstruction which is reversible after treatment with bronchodilator medications (e.g., albuterol). In obliterative bronchiolitis, scar tissue prevents the small airways (bronchioles) from opening up when albuterol is given. In other words, the airways 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].

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

Among the eight participants, two had abnormal breathing tests. The lower respiratory symptoms and breathing test abnormalities are not specific to a particular respiratory problem or disease. They could be related to workplace exposures or to other factors. The upper respiratory symptoms reported to improve away from work were likely related to workplace exposures. 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 found concentrations of diacetyl and 2,3-pentanedione above 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) and bakery employees should participate in the workplace medical monitoring program. A medical monitoring program is a means of early identification of employees who might 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 should be addressed. Grinding roasted coffee beans, packaging coffee, cleaning the roaster, and roasting coffee beans were associated with diacetyl and 2,3-pentanedione levels above the NIOSH RELs, and grinding coffee beans and packaging coffee were associated with 2,3-pentanedione levels above the NIOSH REL; these were likely caused by the close proximity of the employee's breathing zone to the roasted beans. However, five personal CO samples exceeded the NIOSH ceiling level of 200 ppm. Area CO and CO_2 levels were low throughout most of the facility, aside from the grinding area where the highest CO (163.5 ppm) and CO_2 (1280 ppm) levels were observed.

Overall, mucous membrane symptoms, specifically eye, nose, and sinus symptoms, were the most commonly reported symptoms. Some participants noted that their symptoms improved when away from work or were aggravated by exposures at work, including dust and coffee grounds. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom followed by trouble with breathing. No participants reported that these lower respiratory symptoms were work-related or aggravated by an exposure at work. Two of eight participants had abnormal breathing tests. We recommend a medical monitoring program to identify any employees who might be developing lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease. All production employees, employees who assist with production tasks (e.g., roasting, interacting with open storage bins/containers of roasted coffee, grinding, weighing, or packaging coffee), and bakery employees should participate in the workplace medical monitoring program.

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. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment might be needed.

Engineering Controls

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

1. Consult with a ventilation engineer to install a dilution ventilation system that meets current local mechanical codes. This system should consistently supply fresh, outdoor air to the production space. If properly selected, it could also be used to help heat and cool the production space throughout the year. The system should be operated whenever production activities are ongoing, but it could be shut off during unoccupied

periods. Operating this equipment will help dilute and remove airborne alpha-diketones (e.g., diacetyl and 2,3-pentanedione) and CO as they are generated and help maintain the production space under negative pressure relative to the administrative offices.

2. Consult with a ventilation engineer to install local exhaust ventilation during grinding roasted coffee and weighing and packaging coffee.

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 policies and procedures are followed consistently.

1. Install a CO monitor and alarm in the production area 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. After engineering controls have been installed, 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 might fluctuate day to day based on production schedules, we recommend personal air sampling for diacetyl and 2,3-pentanedione over multiple days.
3. The bakery should be evaluated further to identify sources of alpha-diketone exposure by conducting personal air monitoring for diacetyl and 2,3-pentanedione.
4. Periodically clean the roasters' exhausts in accordance with manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve the efficiency, energy usage, and roaster performance.
5. Include roaster exhaust checks and any future local exhaust systems in a preventive maintenance schedule to ensure they operate appropriately.
6. Continue to cover bins of roasted beans to reduce the overall emission of alpha-diketones and other chemicals (e.g., CO, CO_2) into the workplace and lower worker exposure.
7. To reduce exposures to VOCs (including alpha-diketones), CO, and CO_2, minimize production tasks that require employees to place their heads inside the roasted bean bins.
8. Do not blend roasted beans by hand. Instead, use the agitator of the cooling drum or some other automatic mechanism that minimizes employee contact with roasted beans during blending.
9. Eliminate the use of compressed air and dry sweeping as much as possible during cleaning. Instead, use a vacuum system with a high-efficiency particle air filter and wet

methods whenever possible.

10. 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. 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.
11. 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 respiratory protection as personal protective equipment depends on avoiding breakdowns in implementation can cause insufficient protection from respiratory exposures. Proper use of respiratory protection (respirators) requires a comprehensive respiratory protection program and a high level of employee and management involvement and commitment to assure that the right type of respirator is chosen for each hazard, respirators fit users and are maintained in good working order, and respirators are worn when they are needed. Supporting programs such as training, change-out schedules, and medical assessment 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 respiratory protection is used, NIOSH-certified respirators should be fitted with organic vapor cartridges and particulate filters. The choice of respirator should be guided by personal exposure sampling for diacetyl and 2,3-pentanedione NIOSH 2004). Respirators have assigned protection factors (APF). APF refers to the highest level of protection a properly selected respirator can provide. For instance, air-purifying half-face respirators have an 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.

Please be aware that disposable N95 filtering facepiece respirators are not protective against alpha-diketones (diacetyl, 2,3-pentanedione, or 2,3-hexanedione). In cases of dual exposure to dust and alpha-diketones, NIOSH-certified organic vapor cartridges (for the alpha-diketones) and particulate cartridges/filters (for the dust) would be warranted.

Medical Monitoring

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

1. Institute a medical monitoring program for employees who work or assist in the coffee production area or bakery. 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 there was a breakdown in exposure controls and there is potential risk for co-workers. Should this occur, the unanticipated source of exposure must be identified and brought under control. In addition, increased intensity of medical surveillance would be required for all employees performing similar job tasks or having similar or greater potential for exposure. The NIOSH Criteria Document provides detailed guidance on responses to such sentinel events [NIOSH 2016].

Smoking Cessation Program

In a workplace with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier. None of the participants reported current cigarettes smoking. However, if other employees smoke, 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. OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, January–February 2017.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N (%)
Diacetyl	Personal	Bakery	2	2 (100%)	7.7	8.5	2 (100%)
Diacetyl	Personal	Production Area	5	5 (100%)	12.8	40.5	5 (100%)
Diacetyl	Personal	Production Office	4	4 (100%)	7.4	30.4	4 (100%)
Diacetyl	Personal	QC Lab	2	2 (100%)	7.5	12.7	2 (100%)
Diacetyl	Personal	Roasting	2	2 (100%)	19.5	34.7	2 (100%)
Diacetyl	Area	Admin	2	2 (100%)	4.1	6.6	N/A
Diacetyl	Area	Bakery	2	2 (100%)	6.3	6.8	N/A
Diacetyl	Area	Café	4	4 (100%)	3.0	29.0	N/A
Diacetyl	Area	Green Bean Storage	2	1 (50%)	<0.5	3.5	N/A
Diacetyl	Area	Grinding	2	2 (100%)	19.5	28.6	N/A
Diacetyl	Area	Maintenance Shop	2	2 (100%)	2.0	4.7	N/A
Diacetyl	Area	Packaging	4	4 (100%)	10.7	61.2	N/A
Diacetyl	Area	QC Lab	2	2 (100%)	6.4	11.7	N/A
Diacetyl	Area	Roasted Bean Storage	4	4 (100%)	19.3	41.3	N/A
Diacetyl	Area	Roasting	2	2 (100%)	20.8	36.2	N/A
Diacetyl	Area	TRAINING CENTER	2	2 (100%)	6.2	10.6	N/A
Diacetyl	Area	WAREHOUSE	2	2 (100%)	7.6	12.3	N/A
2,3-Pentanedione	Personal	Bakery	2	2 (100%)	4.8	5.8	0 (0%)
2,3-Pentanedione	Personal	Production Area	5	5 (100%)	10.4	27.1	5 (100%)
2,3-Pentanedione	Personal	Production Office	4	4 (100%)	6.9	21.2	1 (25%)
2,3-Pentanedione	Personal	QC Lab	2	2 (100%)	5.4	10.1	1 (50%)
2,3-Pentanedione	Personal	Roasting	2	2 (100%)	16.6	25.1	2 (100%)
2,3-Pentanedione	Area	Admin	2	2 (100%)	3.3	5.0	N/A
2,3-Pentanedione	Area	Bakery	2	2 (100%)	4.5	4.7	N/A
2,3-Pentanedione	Area	Café	4	4 (100%)	2.4	17.5	N/A
2,3-Pentanedione	Area	Green Bean Storage	2	1 (50%)	<0.5	1.6	N/A
2,3-Pentanedione	Area	Grinding	2	2 (100%)	15.4	20.6	N/A
2,3-Pentanedione	Area	Maintenance Shop	2	1 (50%)	<0.3	1.4	N/A
2,3-Pentanedione	Area	Packaging	4	4 (100%)	9.4	38.0	N/A
2,3-Pentanedione	Area	QC Lab	2	2 (100%)	5.6	8.9	N/A
2,3-Pentanedione	Area	Roasted Bean Storage	4	4 (100%)	17.2	28.4	N/A
2,3-Pentanedione	Area	Roasting	2	2 (100%)	17.6	29.3	N/A

Table A1 (cont.). OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, January–February 2017.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N (%)
2,3-Pentanedione	Area	TRAINING CENTER	2	2 (100%)	5.5	8.3	N/A
2,3-Pentanedione	Area	WAREHOUSE	2	2 (100%)	6.6	9.7	N/A
2,3-Hexanedione	Personal	Bakery	2	2 (100%)	0.3	0.3	-
2,3-Hexanedione	Personal	Production Area	5	3 (60%)	<0.2	1.3	-
2,3-Hexanedione	Personal	Production Office	4	0 (0%)	<0.2	<0.3	-
2,3-Hexanedione	Personal	QC Lab	2	1 (50%)	<0.2	0.3	-
2,3-Hexanedione	Personal	Roasting	2	1 (50%)	<0.2	1.2	-
2,3-Hexanedione	Area	Admin	2	0 (0%)	<0.2	<0.3	N/A
2,3-Hexanedione	Area	Bakery	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Café	4	1 (25%)	<0.2	0.9	N/A
2,3-Hexanedione	Area	Green Bean Storage	2	0 (0%)	<0.2	<0.4	N/A
2,3-Hexanedione	Area	Grinding	2	1 (50%)	<0.2	0.6	N/A
2,3-Hexanedione	Area	Maintenance Shop	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Packaging	4	3 (75%)	<0.2	1.4	N/A
2,3-Hexanedione	Area	QC Lab	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Roasted Bean Storage	4	2 (50%)	<0.2	0.9	N/A
2,3-Hexanedione	Area	Roasting	2	1 (50%)	<0.2	1.2	N/A
2,3-Hexanedione	Area	TRAINING CENTER	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	WAREHOUSE	2	0 (0%)	<0.2	<0.2	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 the limit of detection (LOD); < indicates below the LOD; <= indicates less than or equal to the LOD; Above REL N=number of samples above the NIOSH recommended exposure limit (REL); ppb=parts per billion; N/A indicates that NIOSH RELs are specified for personal air samples, and cannot be directly applied to area air samples "-" indicates there is currently no REL for 2,3-hexanedione.

Table A2. Summary of personal short-term task-based measurements, January-February 2017

Analyte	Sample Type	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (range) Sample Duration (minutes)
Diacetyl	Personal	Cleaning Roaster	2	2 (100%)	11.3	28.7	15
Diacetyl	Personal	Grind coffee beans	5	5 (100%)	53.2	66.9	13 (5-15)
Diacetyl	Personal	Package coffee	13	13 (100%)	14.0	56.0	15
Diacetyl	Personal	Roast coffee beans	12	12 (100%)	7.2	25.6	15
2,3-Pentanedione	Personal	Cleaning Roaster	2	2 (100%)	8.4	18.1	15
2,3-Pentanedione	Personal	Grind coffee beans	5	5 (100%)	32.3	53.8	13 (5-15)
2,3-Pentanedione	Personal	Package coffee	13	13 (100%)	12.1	46.6	15
2,3-Pentanedione	Personal	Roast coffee beans	12	12 (100%)	7.1	25.1	15
2,3-Hexanedione	Personal	Cleaning Roaster	2	0 (0%)	<0.7	<0.7	15
2,3-Hexanedione	Personal	Grind coffee beans	5	4 (80%)	<0.7	2.8	13 (5-15)
2,3-Hexanedione	Personal	Package coffee	13	11 (85%)	<0.7	2.2	15
2,3-Hexanedione	Personal	Roast coffee beans	12	1 (8%)	<0.7	0.9	15

Note: 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 STEL N (%)=number of samples above the NIOSH short-term exposure limit (STEL); ppb=parts per billion.

Table A3. Instantaneous evacuated canister method* air sampling results by source, NIOSH survey, January-February 2017

Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Bagging at the matrix frac bagger; using vacuum to fill feed hopper from barrel; breathing zone over barrel when vacuuming; 75 percent medium and 25 percent dark Guatamalan	23.8	16.6	<1.0
Bagging at the matrix frac bagger; using vacuum to fill feed hopper from barrel; breathing zone over barrel when vacuuming; 75 percent medium and 25 percent dark Guatamalan	40.9	35.1	1.5
Bagging at the matrix frac bagger; using vacuum to fill feed hopper from barrel; breathing zone over barrel when vacuuming; 75 percent medium and 25 percent dark Guatamalan	26.2	20.0	<1.1
Bagging at the matrix frac bagger; using vacuum to fill feed hopper from barrel; breathing zone over barrel when vacuuming; 75 percent medium and 25 percent dark Guatamalan	32.3	28.7	1.3
Bagging at the matrix frac bagger; using vacuum to fill feed hopper from barrel; breathing zone over barrel when vacuuming; 75 percent medium and 25 percent dark Guatamalan	30.1	28.0	1.1
Bagging at the matrix frac bagger; using vacuum to fill feed hopper from barrel; breathing zone over barrel when vacuuming; 75 percent medium and 25 percent dark Guatamalan	59.1	57.5	2.4
Bagging at weight right- using vacuum in plastic tub; whole bean	48.2	30.3	1.9
Bagging at weight right- using vacuum in plastic tub; whole bean	42.8	31.9	1.8
Bagging at weight right- using vacuum in plastic tub; whole bean	42.7	27.9	1.5
Bagging at weight right; at dispenser; fill 5 lb bags with whole bean; dark roast	42.9	30.0	1.7
Bagging at weight right; at dispenser; fill 5 lb bags with whole bean; medium roast	36.1	28.6	1.8
Bagging at weight right; at dispenser; fill 5 lb bags with whole bean; medium roast	58.9	50.6	3.3
Frac packaging; emptying frac bags back into ground coffee container	5.7	6.6	<1.0
Frac packaging; suck up ground coffee via tube	27.2	20.6	2.4
Frac packaging; suck up ground coffee via tube	30.4	30.1	1.9
Manual mixing of ground coffee inside metal container	148	94.7	4.1
Scooping whole beans into grinder	52.4	43.2	2.8
Working over cooling bin	24.9	22.9	1.3
Working over cooling bin	30.5	24.1	1.1

Note: 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 A4. Instantaneous evacuated canister method* air sampling results by source, NIOSH survey, January-February 2017

Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Five inches above whole dark beans being scooped into grinder; decaf	91.5	44.1	2.3
Above bins in middle of off gas area; two bins high, 28 bins; 80 pounds per bin	71.3	53.2	4.0
At mouth of grinder nozzle into barrel; decaf	4746	1845	82.7
Directly over bag of medium roast; five pound bag	139	159	<9.4
Directly over bag of medium roast; five pound bag	344	468	20.2
Directly over cooling bin of dark French roast	31.7	18.9	2.8
First small grinder; into a bag of medium roast; directly above bag mouth	1473	1249	41.4
First small grinder; into a bag of medium roast; directly above bag mouth	9062	6897	270
In a bin of dark roast; 24 hours after roast; ready to be mixed into a blended coffee	63.9	31.4	1.7
In a bin of light/med roast; four hours after roasting	467	499	<9.6
In a bin of light/medium roast; four hours after roasting	122	131	<10.2

Note: ppb=parts per billion; < indicates below the limit of detection for the instrument used to detect 2,3-hexanedione.
***Sampling duration approximately 30 seconds; source air samples were collected by placing the inlet of the canister sampler near roasted beans.**

Table A5. Real-time air monitoring results for carbon monoxide (CO), carbon dioxide (CO_2), temperature, and relative humidity (RH), NIOSH survey, January-February 2017

Work Area	CO Range (Average) ppm	Range (Average) ppm	Temperate Range (Average) °F	Relative Humidity Range (Average)
Grinding	1.2-163.5 (6.5)	470-1219 (627.4)	–	–
Packaging	2.1-35.8 (8.8)	271-968 (684.3)	66.1-77.1 (73.9)	–
Roasting	0.9-38.6 (7.29)	487-1231 (703.24)	77.4-88.3* (84.2)	13.2-22.7* (15.18)
QC Lab	0.9-6.4 (1.9)	531-1280 (677.2)	66.7-81.1† (77.4)	17.8-32.3† (22.67)
Bakery‡	1.1-4.5 (1.9)	531-1059 (602.3)	66.7-81.1 (77.4)	17.8-32.3 (22.66)

Note: NIOSH=National Institute for Occupational Safety and Health; ppm=parts per million; "–"Nothing recorded during the sampling period; *Roasting temperature or relative humidity was not recorded on 02/01/2017; †QC Lab temperature or relative humidity was not recorded on 01/31/2017; ‡Sampling only occurred on 02/01/2018 in the bakery

Table A6. Personal air sampling for carbon monoxide, NIOSH survey, January-February 2017

Sample Location	Job Title	CO (ppm) Minimum	CO (ppm) Maximum	CO (ppm) Average
Production Area	Production Employee	0	467	7.16
Roasting	Roaster	0	60	4.54
Production Area	Production Employee	0	617	10.93
Quality Control Lab	Coffee Quality Specialist	0	11	2.62
Production Area	Production Employee	0	425	9.92
Roasting	Roaster	0	55	7.70
Production Area	Production Employee	2	836	11.68
Production Office	Assistant Production Manager	0	304	8.20
Production Office	Production Manager	0	8	0.93
Bakery	Director of Kitchen Operations	0	18	1.15
Quality Control Lab	Coffee Quality Specialist	0	20	2.67

Note: NIOSH=National Institute for Occupational Safety and Health; CO=carbon monoxide.

Table A7. Headspace analysis results* for bulk samples of roasted coffee beans, NIOSH survey, January-February 2017

Sample Type	**Bulk Sample Description**	**Diacetyl (ppb)**	**2,3-Pentanedione (ppb)**	**2,3-Hexanedione (ppb)**
Coffee beans	Light Ring of Fire	102	255	< 212
Coffee beans	Decaffeinated Cream City	< 86	208	< 212
Coffee beans	Light El Salvador	323	500	< 212
Coffee beans	Dark Guatemala	< 86	201	< 212

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion. < indicates that the sample was less than the limit of detection.
***The roasted coffee beans off-gassed for different amounts of time, and this could be responsible for some of the differences in headspace analysis results.**

Table A8. Prevalence of reported symptoms, NIOSH medical survey, February 2017

Symptom	Experienced in the last 12 months N = 8 Number (%)	Experienced in the last 4 weeks N = 8 Number (%)
Nose symptoms*	7 (88%)	5 (63%)
Eye symptoms†	4 (50%)	3 (38%)
Sinusitis or sinus problems	4 (50%)	2 (25%)
Problem with ability to smell	2 (25%)	-
Phlegm on most days for 3 months	1 (12.5%)	-
Lower respiratory symptoms (reported at least one of the following)	2 (25%)	0 (0%)
Breathing trouble	1 (13%)	1 (13%)
Chest wheezing or whistling	2 (25%)	0 (0%)
Awoke with chest tightness	0 (0%)	0 (0%)
SOB on level ground or walking up a slight a hill	0 (0%)	-
Awoke with shortness of breath	0 (0%)	0 (0%)
Asthma attack	0 (0%)	0 (0%)
Usual cough	0 (0%)	0 (0%)
Systemic symptoms (reported at least one of the following)	4 (50%)	0 (0%)
Flu-like achiness or achy joints	4 (50%)	0 (0%)
Fever or chills	0 (0%)	0 (0%)
Unusual tiredness or fatigue	0 (0%)	0 (0%)

Note: N=number of participants; SOB=shortness of breath; "-"= A four week question was not asked for the symptom.
***Nose symptoms includes one or both of the following: 1) stuffy, itchy, or runny nose or 2) stinging, burning nose.**
†Eye symptoms includes one or both of the following: 1) watery, itchy eyes or 2) stinging, burning eyes.

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The Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 (29 U.S.C. § 669(a)(6)). The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations (42 CPR Part 85).

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Availability of Report

Copies of this report have been sent to the employer and employees at the facility. The state 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/2016-0141-3329.pdf.

All other Health Hazard Evaluation Reports may be found at http://www2a.cdc.gov/hhe/search.asp.

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