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

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Contents

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

Highlights of this Evaluation

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

What We Did

- We visited the coffee processing facility in June 2016.
- We collected full-shift (hours), tasks (minutes), and instantaneous (seconds) air samples to measure air levels of the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione over multiple days.
- 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.

What We Found

- On full shift sampling, some employees were exposed to diacetyl concentrations above the recommended exposure limit of 5 parts per billion. The highest concentration of diacetyl we measured as an average across a full shift was 18.8 parts per billion.
- On full shift sampling, some employees were exposed to 2,3-pentanedione concentrations above the recommended exposure limit of 9.3 parts per billion. The highest 2,3-pentanedione concentration we measured as an average across a full shift was 18.7 parts per billion.

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 roasting, grinding, and packaging. Some employees in the production area of the facility had full-shift time-weighted average exposures exceeding the NIOSH recommended exposure limits for diacetyl and 2,3-pentanedione. Additionally, some 15-minute short-term exposure samples collected on employees performing grinding of roasted coffee beans exceeded the recommended NIOSH short-term exposure limits for diacetyl and 2,3-pentanedione. The highest personal carbon monoxide levels were observed on production employees while grinding 5-pound bags of roasted coffee; however, all personal carbon monoxide measurements were below the NIOSH recommended exposure limit of 35 ppm. Eye, nose, and sinus symptoms were the most commonly reported symptoms. Wheezing was the most commonly reported lower respiratory symptom and two times as common as expected. One of 15 participants had abnormal spirometry. We recommend engineering controls to mitigate exposure to diacetyl, 2,3-pentanedione, and carbon monoxide near the grinder and roaster. We provide several additional means to reduce potential employee exposure to diacetyl, 2,3-pentanedione, and carbon monoxide. We also recommend implementing administrative controls such as modification of work practices, training employees about work-place hazards, and instituting a medical monitoring program.

- Levels of diacetyl and 2,3-pentanedione in the air during short-term sampling were higher for tasks involving grinding roasted coffee (maximum 70 parts per billion for diacetyl and 84.0 parts per billion for 2,3-pentanedione).
- The highest levels of carbon monoxide and total volatile organic compound measurements were observed while an employee ground roasted beans for 5-pound bags of coffee.
- The two air-handling units kept the air in the production area from entering the café, breakroom, and office areas. No exposure levels in the café, breakroom, or office areas exceeded the recommended exposure limits for diacetyl or 2,3-pentanedione.
- Eye, nose, and sinus symptoms were the most commonly reported symptoms.
- Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom; two times as many employees reported wheezing as expected.
- One of 15 participants had mildly abnormal spirometry that did not improve after bronchodilator treatment.
- Three of 15 participants had high exhaled nitric oxide, a marker of allergic airways inflammation.

What the Employer Can Do

- Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, carbon monoxide, carbon dioxide, green and roasted coffee dust) in the workplace and how to protect themselves.
- Install local exhaust ventilation systems at the grinder and auto-fill packaging machine to capture diacetyl, 2,3-pentanedione, and carbon monoxide emissions when these machines are in use.
- If possible, increase airflow of downdraft table at the roaster or consider installing additional local exhaust ventilation at the roaster to capture diacetyl and 2,3-pentanedione emissions when the roaster is in use.
- Continue to cover bins of roasted beans to reduce emissions of alpha-diketones, carbon monoxide, and carbon dioxide into the air.
- Ensure the continuous operation of the air handling unit in the production space at all times during production activities.
- Automate transfer of roasted beans, whenever possible, to minimize manual handling.
- Minimize production tasks that require employees to place their heads directly above or inside roasted bean storage bins.
- Follow manufacturer's guidelines for periodic cleaning of the roasters' exhausts.
- Conduct follow-up air sampling to verify the modifications have been effective in reducing exposures to below the recommended exposure limit for diacetyl and 2,3-pentanedione.

- Make N95 disposable filtering-facepiece respirators available for voluntary use for protection against dust exposure such as when emptying burlap bags of green beans into the storage silos, cleaning the exhaust system of chaff, emptying the chaff containers, or cleaning the green bean storage area.
- Encourage employees to report new, worsening, or ongoing respiratory symptoms to their personal healthcare providers and to a designated individual at the workplace.
- Institute a medical monitoring program for employees who work in the production area.

What Employees Can Do

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

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Abbreviations

µm	Micrometer
µg	Microgram
°F	degrees Fahrenheit
ACGIH®	American Conference of Governmental Industrial Hygienists
AHU	Air-handling unit
ANSI	American National Standards Institute
APF	Assigned Protection Factor
AX	Area of reactance
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO2	Carbon dioxide
COHb	Carboxyhemoglobin
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
FEV1	1-second forced expiratory volume
Fres	Resonant frequency
FVC	Forced vital capacity
kg/m2	Kilogram per square meter
kPa/(L/s)	Kilopascals per liter per second
IDLH	Immediately dangerous to life or health
IOM	Institute of Occupational Medicine
LOD	Limit of detection
LOQ	Limit of quantitation
mg/m3	Milligrams per cubic meter of air
mL	Milliliter
mL/min	Milliliter per minute
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppb	Parts per billion
ppm	Parts per million
R5	Resistance at 5 Hertz
R20	Resistance at 20 Hertz
REL	Recommended exposure limit

SMR	Standardized morbidity ratio
STEL	Short-term exposure limit
TLV®	Threshold limit value
TVOC	Total volatile organic compound
TWA	Time-weighted average
U.S.	United States
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

In September 2015, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health (NIOSH) received a request from the management of a coffee roasting and packaging facility regarding concerns about exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting, grinding, and packaging. In June 2016, we conducted a ventilation assessment, an industrial hygiene survey, and a medical survey. The industrial hygiene survey consisted of the collection of air samples and bulk samples of coffee for the analysis of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. Continuous monitoring instruments were used to monitor total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. We also measured levels of carbon monoxide in employees' exhaled breath. The medical survey consisted of a health questionnaire and breathing tests.

Overall, time-weighted average air levels of diacetyl, 2,3-pentanedione, and 2,3-hexanedione were elevated for employees performing duties near the roaster and grinder. Seven of the 10 personal full-shift air samples were above the NIOSH recommended exposure limit for diacetyl of 5 parts per billion, and five of the 10 full-shift air samples were above the recommended exposure limit for 2,3-pentanedione. All personal air samples with diacetyl and 2,3-pentanedione concentrations above the recommended exposure limits were collected on employees with primary job duties in the production area. High full-shift and task-based diacetyl and 2,3-pentanedione exposure measurements were observed on employees that ground coffee. We observed high instantaneous levels of diacetyl and 2,3-pentanedione during grinding. Carbon monoxide and total volatile organic compound levels near the grinder increased sharply when an employee ground roasted beans for 5-pound bags of coffee. Carbon dioxide levels were low throughout most of the facility.

Mucous membrane symptoms, specifically eye, nose, and sinus symptoms, were the most commonly reported symptoms. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom, and was about two times as common as expected compared with the US population of the same age, race/ethnicity, sex, and cigarette smoking distribution. One of the 15 participants had abnormal spirometry. We recommend a combination of engineering and administrative controls to minimize employee exposures. We also recommend a medical monitoring program to identify any employees who might be developing work-related lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease.

Introduction

In September 2015, the National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation at a coffee roasting and packaging facility. The request concerned potential worker exposure to diacetyl and 2,3-pentanedione during the coffee roasting, grinding, and packaging processes and potential lung damage. In June 2016, we visited the facility to learn more about coffee processing and to conduct industrial hygiene and medical surveys. We collected area and personal breathing zone air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We monitored carbon monoxide (CO), carbon dioxide (CO_2), and total VOCs. We also conducted a medical survey.

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 a one-way valve to allow the coffee to off-gas after it is packaged. Sometimes, newly roasted coffee is placed in bins or containers and allowed to off-gas before packaging.

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

These exposure limits and the accompanying recommendations for control of exposures were derived from a risk assessment of flavoring-exposed workers. At an exposure equal to the diacetyl REL, the risk of adverse health effects is low. NIOSH estimated that less than 1 in 1,000 workers exposed to diacetyl levels of 5 parts per billion (ppb) as a time-weighted average (TWA) for 8 hours a day, 40 hours a week for a 45-year working lifetime would develop reduced lung function (defined as forced expiratory volume in one second [FEV_1] below the 5th percentile) as a result of that exposure. NIOSH predicted that around 1 in 10,000 workers exposed to diacetyl at 5 ppb for a 45-year working lifetime would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as at least moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). Workers exposed for less time would be at lower risk for adverse lung effects.

2,3-Hexanedione

2,3-Hexanedione is also an alpha-diketone sometimes used as a substitute for diacetyl and is produced naturally during coffee roasting. In a study using animals, some evidence showed 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]. No established occupational exposure limits exist for 2,3-hexanedione.

Carbon Monoxide and Carbon Dioxide

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

Obliterative Bronchiolitis

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

Work-related Asthma

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

Green and roasted coffee dust and castor beans (from cross-contamination of bags used to transport coffee) are known risk factors for work-related 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 low concentrations in the air. Others can experience irritant-type symptoms from exposure to coffee dust [Oldenburg et al. 2009].

Process Description

In June 2016, the coffee roasting and packaging facility had 19 employees. Eight employees were involved in various administrative tasks which included accounts receivable, customer service, inventory control, delivery, equipment repair, graphic design, sales, and farmer relations. Five employees worked in the café. The remaining six employees were responsible for activities specific to the coffee roasting process. The following describes activities at the time of the NIOSH visit in June 2016.

The coffee roasting process involved four main steps, receiving of green beans (unroasted coffee beans), roasting green beans, weighing and packaging of roasted beans (whole and ground), and shipment or delivery of final product to individual consumers, food cooperatives, restaurants, cafés, and markets.

Green beans were received in burlap bags (sometimes lined with plastic) from various countries around the world including, but not limited to, Colombia, Guatemala, Mexico, and Honduras. Upon arrival at the facility, bags of green beans were stored on pallets either on the floor or shelves until they were dispensed into large green bean storage silos. To prepare a batch for roasting, a roaster operator dispensed the green beans from the storage silo or directly from bags into a container to achieve the proper weight needed for a roast. The green beans were then manually emptied into the hopper of the roaster. The green beans were automatically conveyed from the hopper into the roasting drum where they were heated at a specific temperature and time period until the desired roast was achieved. Time and temperature varied among different types of roasts. At the end of each cycle, the roasted beans were emptied into a cooling drum where they were slowly mixed to accelerate cooling. The cooling drum utilized a downdraft exhaust system that drew air over the roasted beans and down into the cooling drum to accelerate cooling. The downdraft system exhausted out through the roof. A roaster operator monitored the roasting equipment carefully throughout the roasting process. After cooling, the roasted beans were emptied from the cooling drum into plastic storage containers. These containers were then manually moved by a roaster operator to an area where the storage containers were kept. When not in use, the storage containers were covered and stored until needed for grinding or packaging.

For packaging of roasted coffee, a production employee moved a container of roasted beans near the packaging machine. The roasted beans were pneumatically conveyed into the hopper of an automatic auto-fill packaging machine where four different amounts were mainly dispensed for packaging: 12-ounces, 1-pound, 3-pounds, and 5-pounds. For ground coffee, individual, pre-weighed packages of roasted whole beans were emptied into a grinder. The grinder could be adjusted for type of grind (coarse, medium, fine). Packages of both whole and ground coffee were heat-sealed and placed on storage shelves or immediately packed for shipment or local delivery.

The company took measures to ensure quality of green and roasted beans. The facility had a quality control room located in the conference room where roasted beans and brews could be prepared and assessed. Roasted beans were packed in the order they were roasted to ensure freshness. Several employees engaged in "cupping" one to three days per week to ensure quality of roasted coffee.

Various cleaning techniques were used throughout the production area. The chaff collection compartment in the roaster was cleaned using a Shop-Vac vacuum three to four times daily during roasting activities. Once a week the entire roaster was thoroughly cleaned, including the chaff collection compartment, impeller compartment, cooling bin exhaust ducts, and vacuum tube. Sweeping and wiping with dry cloths were conducted daily. Sweeping was performed on the production floor, and wiping was performed on table tops and equipment surfaces. Wet mopping was conducted at least once a week. The grinder was wiped with a clean, dry cloth daily. Once a week the filter on the Pneu-Con vacuum loader was vacuumed.

One employee was involved in repairing of customer's coffee roasting equipment (roasters, grinders, and espresso machines). The company had numerous customers who had their own grinding and brewing equipment for the sale of their coffee. This was a service that the company offered to their customers. The employee would occasionally work on the customer's machines within the production area.

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

Methods

We visited the coffee roasting and packaging facility in June 2016. We held an opening meeting with management and an employee representative; performed a ventilation assessment; collected bulk samples and air samples; conducted confidential medical interviews; and administered breathing tests. At the conclusion of our site visit we held a closing meeting with management and an employee representative. We provided a letter detailing our evaluation and preliminary recommendations to management on July 19, 2016.

1. We had the following objectives for the health hazard evaluation:
2. Measure employees' exposure to diacetyl, 2,3-pentanedione, and 2,3-hexanedione during coffee processing;
3. Identify process areas or work tasks associated with elevated levels of diacetyl, 2,3-pentanedione, and 2,3-hexanedione;
4. Measure levels of CO and CO_2 throughout the facility;
5. Measure CO levels in employees' exhaled breath;
6. Assess ventilation systems and the ventilation systems' effect on exposure levels;
7. Determine if employees had mucous membrane, respiratory, or systemic symptoms and the proportion of those symptoms that were work-related or aggravated by work;
8. Determine if employees had abnormal lung function tests;
9. Compare employees' prevalence of lower respiratory symptoms and physician-diagnosed asthma with 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 identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. For diacetyl, 2,3-pentanedione, and 2,3-hexanedione, air samples were collected over seconds, minutes, and hours. Samples collected over hours can help determine average concentrations that can be compared 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 air samples over several minutes. We also conducted instantaneous sampling over seconds to help identify point sources of alpha-diketones.

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

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

Analyses of the samples were performed in the NIOSH Respiratory Health Division's Organics Laboratory. The samples were extracted for one hour in 95% ethanol:5% water containing 3-pentanone as an internal standard. Samples were analyzed using an Agilent 7890/7001 gas chromatograph/mass spectrometer system operated in selected ion monitoring mode for increased sensitivity compared with 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 an instrument can measure above background and is a criteria used to determine whether to report a result from a sample. The limit of quantitation (LOQ) is the lowest mass that can be reported with precision; we have a greater confidence in the reported result if it is above the LOQ. The LODs were 0.02 micrograms per sample (µg/sample) for diacetyl, 2,3-pentanedione, and 2,3-hexanedione. These equate to 0.6 ppb for diacetyl, 0.5 ppb for 2,3-pentanedione, and 0.5 ppb for 2,3-hexanedione for a typical full-shift TWA air sample but varies depending on the volume of sample collected. The LODs for task samples are generally higher than typical LOD values for full-shift samples because the air volumes collected during task samples are lower. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol. The LOQs equate to 2.0 ppb for diacetyl, 1.7 ppb for 2,3-pentanedione, and 1.7 ppb for 2,3-hexanedione for a typical full-shift air sample.

Air Sampling and Analysis Using Evacuated Canisters

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

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system pursuant to a published method validation study [LeBouf et al. 2012], with the following modifications: the pre-concentrator was a Model 7200 (Entech Instruments, Inc., Simi Valley, CA), and six additional compounds, diacetyl, 2,3-pentanedione, and 2,3-hexanedione, acetaldehyde, acetonitrile, and styrene, were included. At present, this canister method is partially validated [LeBouf et al. 2012] and not considered the standard method. The LODs were 0.78 ppb for diacetyl, 1.08 ppb for 2,3-pentanedione, and 1.92 ppb for 2,3-hexanedione based on a three-times dilution factor. However, LODs are dependent on the pressure inside each canister after the samples have been collected, and they 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.

Continuous (Real-time) Air Sampling

We used a RAE Systems (San Jose, CA) ppbRAE 3000 (Model #PGM-7340) monitor to measure levels of total VOCs in the air near the grinder. This sampling was conducted to identify when peak levels of total VOCs occurred in the area near the grinder. We also collected continuous measurements of CO_2, CO, temperature (in °F), and relative humidity at the roaster and grinder on both days of our survey, using a TSI Incorporated (Shoreview, MN) VelociCalc Model 9555-X Multi-Function Ventilation Meter equipped with a Model 982 IAQ probe.

We also continuously measured employee personal exposures to CO using a Dräger Pac 7000 personal single gas detector (Lübeck, Germany). The Drager Pac 7000 was placed in the breathing zone of employees and worn by employees while they performed their work duties.

Exhaled CO Measurements

We asked employees to perform a carboxyhemoglobin (COHb) test one or more times throughout their shift to measure CO levels in their exhaled breath. This test helps determine if employees are exposed to elevated levels of CO potentially associated with coffee processing activities. Employees were asked to hold their breath for 15 seconds and then exhale through a mouthpiece into a CO monitor. The device then calculated an estimate of COHb in blood. Each employee performing the COHb tests was also asked when he or she had last smoked cigarettes or used tobacco products, electronic cigarettes, or vaporizers, as each of these can cause an increase in exhaled CO.

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)

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

American Conference of Governmental Industrial Hygienist (ACGIH®)

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

National Institute for Occupational Safety and Health (NIOSH)

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

For diacetyl and 2,3-pentanedione, the NIOSH RELs are 5.0 ppb and 9.3 ppb, respectively, as a TWA for up to an 8-hour workday during a 40-hour workweek (Table 1). The NIOSH

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

Table 1. Exposure limits for compounds sampled during the NIOSH survey, June 2016.

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

Note: OSHA=Occupational Safety and Health Administration; ACGIH®=American Conference of Governmental Industrial Hygienist;
NIOSH=National Institute for Occupational Safety and Health; PEL=permissible exposure limit; STEL=short-term exposure limit; TLV®=threshold limit value; REL=recommended exposure limit; IDLH=immediately dangerous to life or health; mg/m³=milligram per cubic meter; ppb=parts per billion; ppm=parts per million; "-"=no exposure limit available.
***There are no OSHA STELs for the compounds in the table.**
†The NIOSH RELs for diacetyl and 2,3-pentanedione are time-weighted averages for up to an 8-hour day, during a 40-hour workweek.
§OSHA and NIOSH limits are designed for occupational exposure measurements in manufacturing and other trades that have potential sources of carbon dioxide or carbon monoxide (e.g., coffee roasting, welding, vehicle exhaust, diesel engine exhaust). Typical levels of carbon monoxide in offices are 0–5 ppm. In office settings, carbon dioxide generally should not be greater than 700 ppm above outdoor carbon dioxide levels; this typically corresponds to indoor concentrations below 1200 ppm.
¶This is the NIOSH ceiling exposure limit for carbon monoxide. A ceiling concentration should not be exceeded at any time.

Ventilation Assessment

On June 28, 2016, we conducted visual and physical assessments of all ventilation components at the facility. Physical measurements of the facility were taken with a Model DISTO E7100i laser-tape measure (Leica Geosystems AG, Heerbrugg, Switzerland). Air flow measurements of supply vents and exhaust outlets were taken using an Accubalance Plus Model 8373 Air Capture Hood (TSI Incorporated, Shoreview, MN) or a VelociCalc Plus Model 8324 Rotating Vane Anemometer (TSI Incorporated, Shoreview, MN). Differential pressure measurements between adjacent spaces were taken under various ventilation scenarios using a DG-500 Pressure Gauge (Energy Conservatory, Minneapolis, MN).

NIOSH Medical Survey

Participants

We invited all current employees and the owner to participate in the medical survey at the workplace during June 29–30, 2016. Participation was voluntary and written informed consent was obtained from each participant before testing. The survey included, in the order performed, a medical and work history questionnaire, quantification of exhaled nitric oxide, impulse oscillometry, spirometry, and if indicated the administration of bronchodilator with repeat impulse oscillometry and spirometry. We mailed participants their individual reports explaining their breathing test results and recommended each participant provide the information to their personal physician.

Questionnaire

We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee processing 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 et al. 1987, 1994], and the Third National Health and Nutrition Examination Survey (NHANES III) [CDC 1996] and NHANES 2007–2012 questionnaires [CDC 2017a]. 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 the lungs. Test results were compared with expected normal values. The test included three measurements or calculations: 1) forced vital capacity (FVC), (the total amount of air the participant can forcefully blow out after taking a deep breath), 2) FEV_1 (the amount of air that the participant can blow out in the first second of exhaling), and 3) the ratio of FEV_1 to FVC. We used American Thoracic Society criteria for acceptability and repeatability [Miller et al. 2005].

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

Impulse Oscillometry

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

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

Bronchodilator Reversibility Testing for Impulse Oscillometry and Spirometry

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

Fractional Exhaled Nitric Oxide (FeNO)

We used the NIOX MINO® device (Aerocrine Inc., Morrisville, NC) to measure the amount of nitric oxide in the air the participant breathed out. Nitric oxide is a gas 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 might indicate their asthma is uncontrolled [Dweik et al. 2011].

Statistical Analysis

Industrial Hygiene Survey and Ventilation Assessment

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

Medical Survey

We calculated frequencies and standardized morbidity ratios (SMRs) using SAS version 9.3 (Cary, NC). The SMRs compare prevalences of symptoms and spirometric abnormalities among participants with expected prevalences of a sample of the general population reflected in the NHANES III (1988–1994, symptom and spirometry data), NHANES 2007–2012 (symptom data), and NHANES 2007–2010 (spirometry data) adjusting for gender, race/ethnicity, age (less than 40 years old or 40 years or greater), and cigarette smoking categories (ever/never). For comparisons with the U.S. population, we used the most recent NHANES survey available for the specific comparisons.

Results

All results tables are located in Appendix A.

Industrial Hygiene Survey

Personal and Area Full-shift Air Sampling Results

Personal and area full-shift TWA air concentrations measured using OSHA Methods 1013/1016 can be seen in Table A1. We collected 10 personal and 18 area full-shift TWA air samples. Seven of the personal air samples were above the NIOSH REL of 5 ppb diacetyl, and five were above the NIOSH REL of 9.3 ppb 2,3-pentanedione. The highest full-shift personal samples for diacetyl (18.8 ppb) and 2,3-pentanedione (18.7 ppb) were collected on employees with multiple tasks and duties in the production area. Employees with personal air samples above the NIOSH REL for diacetyl and 2,3-pentanedione performed roasting, grinding, or packaging.

Twelve area full-shift air samples were above the NIOSH REL for diacetyl. Because area air samples are not personal air samples collected directly on an employee, the NIOSH RELs are not directly applicable to the results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the RELs can be used as points of reference. The following areas had full-shift air levels that exceeded the NIOSH REL for diacetyl: Diedrich roaster (5.1 ppb–11.8 ppb), grinder (8.1 ppb–9.6 ppb), auto-fill packaging machine (8.1 ppb–15.2 ppb), packaging/storage (6.2 ppb–15.0 ppb), and the green bean silo area (5.8 ppb–10.8 ppb). The following areas had full-shift air levels that exceeded the NIOSH REL for 2,3-pentanedione: Diedrich roaster (4.8 ppb–11.2 ppb), packaging/storage (5.8 ppb–15.3 ppb), and the green bean silo area (5.1 ppb–10.6 ppb).

Task-based Air Sampling Results

Personal task-based air concentrations can be seen in Tables A2 and A3. We collected 25 personal task-based air samples using OSHA Methods 1013/1016 (Table A2). Task duration ranged from two minutes to 22 minutes with a median of 16 minutes. We collected personal task air samples while employees roasted coffee (n = 9), ground coffee (n = 8), and packaged coffee (n = 8). We measured the highest exposures to diacetyl (range: 29.8 ppb–68.9 ppb) while employees ground coffee. We collected two 15-minute samples (29.8 ppb, 33.1 ppb) while employees ground coffee; they both exceeded the NIOSH STEL of 25 ppb for diacetyl. Diacetyl exposures measured while employees packaged coffee ranged from 5.8 ppb to 18 ppb; we collected two 15-minute samples (12.7 ppb, 14.2 ppb), and they did not exceed the NIOSH STEL for diacetyl. Task-based air samples during coffee roasting ranged from 2.2 ppb to 9.5 ppb for diacetyl; we collected one 15-minute sample (3.4 ppb), and it did not exceed the NIOSH STEL for diacetyl.

Task exposures to 2,3-pentanedione were similar to the diacetyl exposures described above. We measured the highest exposures to 2,3-pentanedione (range: 29.6 ppb–84.0 ppb) while employees ground coffee. One of the two 15-minute samples (29.6 ppb, 33.3 ppb) we collected on employees grinding coffee exceeded the NIOSH STEL of 31 ppb for 2,3-pentanedione. 2,3-Pentanedione exposures measured while employees packaged coffee ranged from 6.7 ppb to 15.7 ppb; we collected two 15-minute samples (12.9 ppb, 14.6 ppb), and they did not exceed the NIOSH STEL for 2,3-pentanedinoe. Task exposures during coffee roasting ranged from 2.6 ppb to 10.1 ppb for 2,3-pentanedione. We collected one 15-minute sample (3.5 ppb), and it did not exceed the NIOSH STEL for 2,3-pentanedione.

We collected 18 personal samples near the breathing zone of an employee using instantaneous canisters (Table A3). We measured the highest personal instantaneous samples while employees ground coffee (range: diacetyl, 30.8 ppb–50.4 ppb; 2,3-pentanedione, 28.6 ppb–46.6 ppb). Instantaneous personal samples collected while employees used the auto-fill packaging machine ranged from 16.9 ppb to 21.5 ppb for diacetyl and 14.1 ppb to 22.1 ppb for 2,3-pentanedione. Instantaneous diacetyl and 2,3-pentanedione concentrations measured at the breathing zone of employees while they pulled a sample of beans from the roaster to check the quality of the roasted beans ranged from 11.5 ppb to 21.4 ppb for diacetyl and 10.3 ppb to 17.7 ppb for 2,3-pentanedione. Instantaneous samples collected while employees dumped beans from the roaster's cooling bin into plastic storage bins had concentrations ranging from 8.0 ppb to 22.6 ppb for diacetyl and 5.5 ppb to 15.8 ppb for 2,3-pentanedione. Samples collected while an employee vacuumed chaff from the roaster exhaust ranged from 13.3 ppb to 14.5 ppb for diacetyl and 11.8 ppb to 13.6 ppb for 2,3-pentanedione.

Source Air Sampling Results

Instantaneous evacuated canister concentrations for diacetyl and 2,3-pentanedione can be seen in Table A4. Instantaneous samples were less than 30 seconds in duration. We collected three instantaneous source samples using evacuated canisters. Diacetyl and 2,3-pentanedione concentrations near the transfer point of the auto-fill machine during packaging of 12 oz or 5-pound bags ranged from 5.5 ppb to 9.1 ppb for diacetyl and 4.5 ppb to 7.0 ppb for 2,3-pentanedione.

Beginning and End of Day Air Sampling

We collected instantaneous samples using evacuated canisters at the beginning of the production shifts on June 27 and 28, 2016, and the end of production on June 28, 2016. All three samples were taken in the center of the production floor. The beginning of day diacetyl air concentration was 11.3 ppb on June 27, 2016, and 5.7 ppb on June 28, 2016, and the 2,3-pentanedione air concentration was 9.8 ppb on June 27, 2016, and 3.2 ppb on June 28, 2016. The end of day diacetyl air concentration on June 28, 2016, was 11.1 ppb and the 2,3-pentanedione air concentration was 9.7 ppb.

Bulk Samples and Headspace Results

Headspace results of diacetyl and 2,3-pentanedione for the bulk samples of roasted coffee beans can be seen in Table A5. The highest air concentration of diacetyl (3,434 ppb) and 2,3-pentanedeione (4,145 ppb) was observed in the headspace of a decaffeinated roast. All headspace results for 2,3-hexanedione for the bulk samples of roasted coffee were below the LOD.

Real-time Monitoring: Carbon Dioxide (CO_2), Carbon Monoxide (CO), and Total Volatile Organic Compounds (VOCs)

A summary of the real-time CO, CO_2, temperature, relative humidity, and total VOC area monitoring results can be seen in Table A6. Overall, levels of CO_2 and CO were consistent between the two days of our survey. At the roaster, we measured 295 ppm to 957 ppm for CO_2 and <0.1 ppm to 4.2 ppm for CO. At the grinder, we measured 194 ppm to 1,259 ppm for CO_2 and <0.1 ppm to 90.2 ppm for CO. We measured peak levels of CO_2 (maximum of 1,259 ppm) and CO (maximum of 90.2 ppm) at the grinder when an employee ground 5-pound bags of roasted coffee. Total VOC measurements at the grinder ranged from 31 ppm to 13,012 ppm, with an average of 484 ppm across the two days of our survey.

A summary of continuous, personal measurements of CO can be seen in Table A7. TWA personal CO measurements ranged from <1 ppm to 3.7 ppm and were below the NIOSH REL of 35 ppm for CO exposure. We observed the highest CO levels (maximum 63 ppm) on production employees while they ground 5-pound bags of roasted coffee.

Personal Exhaled Carbon Monoxide (CO) Measurements

Seven employees that participated in the personal air sampling also provided breath samples for measurement of CO by exhaling into a monitor at various times during the workday. Measurements were typically collected at the beginning of the shift, lunch break, and at the end of the shift. After exhaling into the monitor, the device reported a CO value in ppm and also calculated an estimated COHb percentage. The overall average CO level was 5.7 ppm (range: 0 ppm–24 ppm) and the average COHb percentage was 1.5% (0–4.5%). The average CO level in smokers was 11.1 ppm (range: 3 ppm–24 ppm) and the average COHb percentage was 2.4% (range: 1.1%–4.5%). All COHb test results in non-smokers were below 1.4% and in smokers were below 4.5%.

Ventilation Assessment Results

Two air-handling units (AHU's) were in use on the days of our survey. One AHU supplied air to the office and café areas, and the second AHU supplied air to the production area. The production space was under negative pressure relative to the office and café areas when both AHU's were on and when both AHU's were off. An accessory fan placed near the grinder was operated whenever coffee was ground. An adequate supply of outdoor air, typically delivered through the heating, ventilation, and air-condition system, is necessary in any occupied spaces to dilute pollutants that are released by equipment, processes, products, and people. We were unable to accurately measure the amount of fresh, outdoor air being provided by the AHU to the production area. The outdoor air supply may be sufficient, at least during certain parts of the year. If the amount of outdoor air supplied to the space is low, however, increasing the outdoor air flow will provide more dilution and removal of airborne contaminants from the space. Consistently supplying the production space with appropriate outdoor air may not bring all personal exposures to diacetyl and 2,3-pentanedoine below the NIOSH RELs, but it is an inexpensive, easy place to start engineering control improvements. Providing more outdoor air flow will enhance dilution and removal of contaminants, but there will be additional energy costs associated with heating and cooling that outside air for much of the year. Those decisions should be made as part of an overall plan to improve engineering controls at the facility. A ventilation system expert can help meet all ventilation requirements in the production space and other areas of the building occupied by employees.

Medical Survey

Demographics

Fifteen (79%) of 19 onsite employees present during June 29–30, 2016, participated in the medical survey, including all production employees. Six (40%) participants were male, 14 (93%) were white, and the median age was 32 years (range: 23–55 years). Median tenure at the facility was 1.3 years (range: 0–7.0 years). Six participants had previously worked at other coffee production facilities; among these, median tenure in the coffee industry was 2.9 years (range: 0–10.5 years). Eight (53%) participants were current smokers or former smokers.

All 15 participants reported spending time in the production area of the facility during the work week. Of the 15 participants, 14 reported being within an arm's length of the roaster while it was operating and the cooling bins that contain roasted coffee beans that were cooling. All participants reported being within an arm's length of the production grinder while it was operating.

Symptoms and Self-Reported Diagnoses

The prevalences of symptoms over both the last 12 months and four weeks reported at the time of the survey are listed in Table A8. Mucous membrane symptoms were the most commonly reported symptoms over the past 12 months, specifically nose symptoms (n=12, 80%) and eye symptoms (n=7, 47%). Some production employees noted these symptoms were caused or aggravated by green coffee bean dust, cleaning the roasting machine, and packaging roasted beans. Three participants reported their mucous membrane symptoms were better when away from work.

Five (33%) participants reported one or more lower respiratory symptoms in the past 12 months: cough, awoke with chest tightness, awoke with shortness of breath, chest wheezing or whistling, asthma attack, breathing trouble, or shortness of breath on level ground or walking up a slight hill. One of these five participants reported lower respiratory symptoms in the 4 weeks before the medical survey. Two employees reported their lower respiratory symptoms were aggravated by work or better when away from work.

Two participants reported a history of nasal allergies, two eczema, one asthma, and one gastroesophageal reflux disease. All these conditions were diagnosed before employment at the coffee processing facility. No participants reported a diagnosis of chronic bronchitis, bronchiolitis obliterans, interstitial lung disease, hypersensitivity pneumonitis, chemical pneumonitis, sarcoidosis, heart disease, or vocal cord dysfunction.

Medical Tests

One spirometry test was interpreted as having a mild restrictive pattern with no significant improvement after bronchodilator. Two oscillometry tests were interpreted as consistent with a large airway abnormality, and one was interpreted as consistent with a small airway abnormality. Three exhaled nitric oxide tests were interpreted as elevated. One half of participants with abnormalities on medical tests were current or former smokers. Two participants with abnormalities on medical tests reported lower respiratory symptoms, such as wheezing, that did not improve away from work.

NHANES Comparison of Symptoms, Diagnoses, and Spirometry

The SMR for wheezing was elevated at 2.4 (Table A9). The SMRs for cough, phlegm, sinus problems, eye symptoms, and physician-diagnosed asthma were not elevated. In addition, no excess of restrictive spirometry abnormalities were present compared with the general U.S. population, adjusted for age distribution, race/ethnicity, sex, and smoking history.

Discussion

At the coffee roasting and packaging facility that is the subject of this report, the highest area samples for diacetyl and 2,3-pentanedione were observed in areas where coffee was ground (near the grinder). Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other compounds such as CO_2 and CO are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for the off-gassing of these chemicals [Anderson et al. 2003; Akiyama et al. 2003; Daglia et al. 2007; Newton 2002; Nishimura et al. 2003; Raffel and Thompson 2013]. 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 Air Sampling

All personal air samples with concentrations above the NIOSH RELs for diacetyl or 2,3-pentanedione were collected on employees with primary job duties on the production floor. The highest personal full-shift samples were collected on employees with grinding and/or packaging duties. The personal full-shift air sample collected on an employee with primary duties in the office area was below the NIOSH REL for diacetyl and 2,3-pentanedione. As noted earlier, the REL should be used as a guideline to indicate when steps should be taken to reduce exposures in the workplace. The risks associated with the measured levels are higher than NIOSH recommends. As described in the quantitative risk assessment from the NIOSH Criteria Document (Table 5-27) [NIOSH 2016], after a 45-year working lifetime exposure to 10 ppb (a concentration somewhat lower than the highest concentration measured at this facility), NIOSH estimated less than 2 in 1,000 workers would develop reduced lung function (FEV1 below the 5th percentile). NIOSH predicted that around 2 in 10,000 workers exposed to diacetyl at 10 ppb would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as at least moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). After a 45-year working lifetime exposure to 20 ppb (a concentration slightly higher than the highest concentration measured at this facility), NIOSH estimated that 3 in 1,000 workers would develop reduced lung function (FEV_1 below the 5th percentile). NIOSH predicted that 5 in 10,000 workers exposed to diacetyl at 20 ppb would develop more severe lung function reduction. The effects of a working lifetime exposure at 19 ppb would be close to 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 below 1 in 1000 workers.

Area Air Sampling

Areas near the Diedrich roaster, green bean silo storage (located near the roaster), grinder, and the packaging and storage areas had air levels that exceeded the NIOSH REL for diacetyl or 2,3-pentanedione. Elevated levels of diacetyl and 2,3-pentanedione measured near the green bean silo storage were likely caused by the close proximity to nearby sources of alpha diketones to include roasted whole beans and ground coffee in the roasting, packaging and storage, and grinding areas. We note that NIOSH RELs are intended to be directly compared with personal measurements; therefore, an area air sample that exceeds a NIOSH REL is only an indication of potential personal exposures.

Task-Based Exposures

Coffee processing involves multiple tasks that can cause intermittent exposure to diacetyl and 2,3-pentanedione. Traditional full-shift sampling will not characterize these intermittent, peak exposures. The purpose of task-based sampling was to understand what tasks have higher exposures to diacetyl and 2,3-pentanedione. Short-term peak exposures might have effects on the lungs even when full-shift average exposures are relatively low, as has been observed in the microwave popcorn industry [Kanwal et al. 2006].

Our task-based air sampling revealed some tasks had higher air concentrations of diacetyl or 2,3-pentanedione than other tasks. The highest exposure to diacetyl (68.9 ppb) and 2,3-pentanedione (84.0 ppb) were measured while an employee was grinding coffee (Table

A2). The greater surface area for off-gassing that is produced during grinding could have resulted in the higher air concentrations [Akiyama et al. 2003]. All 15-minute samples collected while employees ground coffee exceeded the NIOSH STEL for diacetyl. One of the 15-minute air samples collected while an employee ground coffee was also above the NIOSH STEL for 2,3-pentanedione. No 15-minute samples collected during packaging or roasting tasks exceeded the NIOSH RELs for diacetyl or 2,3-pentanedione. The roaster operator often remained near the roaster control panels, directly adjacent to the roaster cooling bin. The downdraft system on the roaster machine pulled air over the roasted beans and down into the cooling drum to accelerate cooling, and this engineering control likely helped mitigate the roaster operator's exposure.

Instantaneous Sampling
We measured diacetyl and 2,3-pentanedione using instantaneous sampling in which sample duration was less than 30 seconds. These instantaneous samples were collected to identify and describe tasks and point sources of diacetyl and 2,3-pentanedione. The highest instantaneous concentrations for diacetyl and 2,3-pentanedione were taken at the breathing zone of an employee while the employee ground roasted beans for 5-pound bags. The second highest breathing zone instantaneous concentrations for diacetyl and 2,3-pentanedione were observed while an employee was hand-blending six pounds of roasted coffee. The instantaneous breathing zone sampling results for dumping roasted beans from the roaster into the cooling bin were among the lowest we measured during the site visit. Instantaneous source samples taken at the transfer point from the packaging machines were also relatively low. Overall, the instantaneous sampling results suggest the major task and point source of diacetyl and 2,3-pentanedione at this facility is the grinder while grinding coffee beans.

2,3-Hexanedione is another alpha-diketone produced naturally during the coffee roasting process and used in the food industry, although to a lesser extent than diacetyl and 2,3-pentanedione. The respiratory toxicity of 2,3-hexanedione appears to be lower than diacetyl and 2,3-pentanedione, although it is likely not free of toxicity [Morgan et al. 2016]. Across all sample types, results for 2,3-hexanedione were low. The highest levels of 2,3-hexanedione (maximum 1.3 ppb) were obtained in the instantaneous samples that also had the highest levels of diacetyl and 2,3-pentanedione (grinding roasted coffee beans).

Our instantaneous samples collected at the beginning of the day on June 27 and 28, 2016, and at the end of production on June 28, 2016, indicated that background levels of diacetyl can remain elevated even when production activities have ceased overnight. Both samples were taken in the center of the production floor. The beginning of day diacetyl air concentration on June 27, 2016, was 11.3 ppb on June 27, 2016, and 5.7 ppb on June 28, 2016, and the 2,3-pentanedione air concentration was 9.8 ppb on June 27, 2016, and 3.2 ppb on June 28, 2016. The end of day diacetyl air concentration on June 28, 2016, was 11.1 ppb, and the 2,3-pentanedione air concentration was 9.7 ppb. Whole or ground coffee that is off gassing from bags stored in the finished product storage area combined with elevated air levels of alpha diketones from the production activities like grinding and packaging ground coffee without sufficient ventilation to remove alpha diketones might have contributed to the elevated levels of diacetyl even after production activities have ceased.

Bulk samples
Diacetyl is not found in green coffee beans. Rather, diacetyl is generated 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 considerable source of alpha-diketones in the facility. The amount of time beans were roasted, and the amount of time roasted beans off-gassed before the collection of bulk samples could be responsible for differences in headspace analysis results.

Real-time Sampling for CO, $CO_{2,}$ and VOCs
Our real-time monitoring found the highest overall levels of total CO, CO_2, and VOCs were observed at the main grinders when employees were using the coffee grinders. Our real-time monitoring for total VOCs, although not specific for diacetyl or 2,3-pentanedione, highlighted sharp increases in releases of VOCs during the grinding of roasted coffee beans. Measurement of total VOCs included numerous alpha-diketones and many other volatile compounds. The individual levels of each compound included in a total VOC measurement can vary widely [Rhoades 1960; Akiyama 2003, Shibamoto 2015]. We measured the highest levels of total VOCs (13,012 ppb) during the grinding of whole beans for 5-pound bags of coffee. Relocation of the grinder to a dedicated workspace with increased ventilation would help reduce VOC concentrations during these tasks.

Overall, average levels of CO_2 and CO were consistent between the two days of our survey and were all well below ceiling limits. We measured levels of CO_2 and CO at the roaster that ranged from 295 ppm to 957 ppm for CO_2 and <0.1 ppm to 4.2 ppm for CO. Levels at the grinder ranged from 194 ppm to 1,259 ppm for CO_2 and <0.1 ppm to 90.2 ppm for CO. We measured peak levels of CO_2 (maximum of 1,259 ppm) and CO (maximum of 90.2 ppm) at the grinder when an employee ground 5-pound bags of roasted coffee. Average and maximum levels of CO_2 and CO were higher on the first day of the survey. We observed more grinding on the first day of our survey.

None of the average area levels of CO exceeded the NIOSH REL (35 ppm) or OSHA PEL (50 ppm). The highest personal CO levels were observed on production employees while grinding 5-pound bags of roasted coffee. Levels of CO near an employee's breathing zone were as high as 63 ppm and while an employee was grinding 5-pound bags of coffee.

One limitation of interpreting real-time measurements for VOCs, CO_2, or CO, is the results can only be summarized within the context of when tasks were documented. Increases in VOCs, CO_2, or CO might be explained by another task that occurred but not captured in our notes. For example, activity at the nearby grinders might have contributed to the elevated measurements of diacetyl and 2,3-pentanedione for workers performing tasks in the packaging area.

Ventilation
We commend the management on the current configuration of the ventilation system that separates the production room air from the office, café, and breakroom areas. One AHU supplied air to the office, café, and breakroom areas, and the second AHU supplied air to the production area. The production space was under negative pressure, relative to the office and café areas, when both AHU's were on and when both AHU's were off. This

configuration likely contributed to the low personal and area air concentrations of diacetyl and 2,3-pentanedione in the café, breakroom, and office areas.

Medical Survey

Overall, mucous membrane symptoms, specifically eye and nose symptoms, were the most commonly reported symptoms. Some employees reported their mucous membrane symptoms were caused or aggravated by green coffee dust, cleaning the roaster, or packaging roasted coffee. Green and roasted coffee dust and castor beans (from cross-contamination of bags used to transport coffee) are known risk factors for work-related asthma [Figley and Rawling 1950; Karr et al. 1978; Zuskin et al. 1979, 1985; Thomas 1991]. Persons who become sensitized to coffee dust can react to 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 can precede the diagnosis of asthma [Shaaban et al. 2008; EAACI Task Force on Occupational Rhinitis et al. 2008; Rondón et al. 2012, 2017; Sahay et al. 2016]. Upper respiratory involvement (e.g., rhinitis, sinusitis) can result in suboptimal control of asthma. All five participants that reported lower respiratory symptoms also reported nasal or sinus problems or physician-diagnosed hay fever or nasal allergies. Three production workers who reported lower respiratory symptoms also noted that green coffee beans or packaging roasted coffee aggravated their nose or sinuses.

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]. One way to prevent symptoms related to green coffee dust and chaff might be to make N-95 disposable filtering-face piece respirators available for voluntary use when emptying burlap bags of green beans into the storage silos or when emptying the chaff containers or cleaning the green bean storage area.

The number of participants with physician-diagnosed asthma was not different from that observed in the U.S. population. However, 33% (n=5) of participants reported lower respiratory symptoms. Two of these participants 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, intermittent airways obstruction occurs that is reversible after treatment with bronchodilator medications (e.g., albuterol). In obliterative bronchiolitis, scar tissue prevents the small airways (bronchioles) from opening up when albuterol is given. In other words, the airways are fixed and not responsive (reversible) to bronchodilator medicine. The obstructed airways prevent rapid emptying of the lung air sacs (alveoli) during exhalation. This explains why the respiratory symptoms of those with occupational obliterative bronchiolitis do not tend to improve when away from work-related exposures; however, avoidance of further exposure can stop progression of the disease [Akpinar-Elci et al 2004].

Spirometry and impulse oscillometry measure different things. Spirometry assesses airflow and is the breathing test typically used to screen for flavoring-related lung disease. Impulse oscillometry accesses the airways response to a sound or pressure wave and has not commonly been used to screen for flavoring-related lung disease. In general, during the impulse oscillometry test, a small pressure impulse (sound wave) is imposed upon the inspiratory and expiratory airflow during normal tidal breathing. This pressure wave causes a disturbance in the airflow and pressure, and the response of the airways (i.e., change in pressure to change in flow) is a measure of the resistance to airflow in the airways [Desiraju and Agrawal 2016]. Impulse oscillometry might be useful as an indirect measure of airflow obstruction and helpful in persons not able to perform forced breathing maneuvers 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, fewer reference equations are available for oscillometry [Vogel and Smidt 1994; Newbury et al. 2008; Schulz et al. 2013]. The predicted values we used for oscillometry measures were based on gender and age according to references values recommended by the manufacturer. Unlike predictive equations used for spirometry, the impulse oscillometry reference equations we used did not take into account height, race, or smoking status [Vogel and Smidt 1994].

Our findings of upper and lower respiratory symptoms with a work-related pattern in some employees, over two-fold excess of wheeze, and abnormalities on lung function testing in about a 40% of participants suggest a burden of respiratory problems in this workforce. The upper respiratory symptoms that improve away from work are likely related to workplace exposures. However, the lower respiratory symptoms such as wheeze did not have a work-related pattern. These lower respiratory symptoms and the lung function abnormalities we found are not specific to a particular respiratory problem or disease. They could be related to workplace exposures or to other factors. Indeed, some employees had respiratory diagnoses that preceded employment at this facility. Because of the small number of participants and the need to protect individual employee 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 RELs and nine employees had abnormal breathing tests or history of lower respiratory symptoms. All production employees and any employees that assist with production tasks (e.g., roasting, interacting with open storage bins/containers of roasted coffee, grinding, weighing, or packaging coffee) should participate in the workplace medical monitoring program. A medical monitoring program is a means of early identification of employees who 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 2017b].

Conclusions

We identified specific work tasks resulting in air concentrations of diacetyl that exceeded the NIOSH REL and STEL for diacetyl and the REL for 2,3-pentanedione. Seven of the nine personal full-shift air concentrations collected on employees in the production area were above the NIOSH REL of 5 ppb for diacetyl, and five of nine personal full-shift air concentrations measured on employees in the production area were above the NIOSH REL of 9.3 ppb for 2,3-pentanedione. Overall, the highest employee exposures to diacetyl, 2,3-pentanedione, and CO were measured while employees ground roasted coffee beans. Likewise, the highest area samples for total VOCs, CO, diacetyl, and 2,3-pentanedione were observed near the grinder when an employee was grinding coffee. All production floor areas had full-shift concentrations of diacetyl that exceeded the NIOSH REL of 5 ppb for diacetyl and 9.3 ppb for 2,3-pentanedione. In contrast, personal and area levels of diacetyl and 2,3-pentanedione in the café, breakroom, and office areas were consistently low and below the NIOSH RELs for diacetyl and 2,3-pentanedione.

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.

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 local exhaust ventilation at the grinders.
2. Consider relocating the grinders to an area with little or no bystander foot traffic to minimize potential exposure risks to employees not directly using the grinder.

3. Consult with a ventilation engineer to increase the local exhaust ventilation in the downdraft table at the roaster.
4. Consult with a ventilation engineer to install local exhaust ventilation at the auto-fill packaging machine.
5. After engineering controls have been installed at the grinder, roaster, and auto-fill packaging machine, conduct personal air monitoring for diacetyl and 2,3-pentanedione on all employees with primary duties in the production area using OSHA Sampling Method 1012 for diacetyl [OSHA 2008] and OSHA Sampling Method 1016 for 2,3-pentanedione [OSHA 2010]. Because air levels of VOCs like diacetyl and 2,3-pentanedione can fluctuate based on production schedules, we recommend personal air sampling for diacetyl and 2,3-pentanedione over multiple days.

Administrative Controls

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

1. Whenever possible, employees should avoid spending time in the immediate area where coffee is being ground or ground coffee is being packaged.
2. Continue to cover bins of roasted beans to aid in reducing the overall emission of alpha-diketones and other chemicals (e.g., CO, CO_2) into the workplace.
3. Continue to periodically clean the roaster's exhaust according to manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve the efficiency, energy usage, and roaster performance.
4. Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, CO, CO_2, dust) in the workplace and how to protect themselves. OSHA's *Hazard Communication Standard*, also known as the "*Right to Know Law*" [29 CFR 1910.1200] requires employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.
5. Ensure employees are educated to consider the risks of further exposure if they develop lower respiratory symptoms (e.g., cough, shortness of breath, wheezing) that are progressive and severe in degree. Employees should report new, persistent, or worsening symptoms to their personal healthcare providers and to a designated individual at this workplace. Employees with new, persistent, or worsening symptoms should share this report with their healthcare providers.

Personal Protective Equipment

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

1. In addition to engineering and administrative controls, respiratory protection is a potential option to further reduce exposures to alpha-diketones (e.g., diacetyl and 2,3-pentanedione). If follow-up air sampling after engineering controls have been installed indicates levels of diacetyl and 2,3-pentanedione above their respective NIOSH RELs and STELs, we recommend respiratory protection be used during tasks with elevated exposures. If respiratory protection is used, NIOSH-certified respirators should be fitted with organic vapor cartridges and particulate filters. The choice of respirator should be guided by personal exposure sampling for diacetyl and 2,3-pentanedione (NIOSH 2004). Respirators have assigned protection factors (APFs). APF refers to the highest level of protection a properly selected respirator can provide. For instance, air-purifying half-face respirators have an APF of 10, and air-purifying full-face respirators have an APF of 50. Also, there are powered-air purifying respirators that have APFs of 25, 50, or 1000. The OSHA APFs can be found in Table 1 of OSHA Respiratory Protection Standard at https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716.

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

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

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

3. We did not formally assess noise during our visits. A noise survey would be necessary to determine the need for hearing protection and inclusion in a hearing conservation program. In the interim, continue to offer hearing protection for voluntary use in the production area.

Medical Monitoring

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

1. Institute a medical monitoring program for employees who work or assist in the production area. The medical monitoring should consist of evaluation with a questionnaire (to obtain health and work task information) and spirometry (to assess lung function) at baseline and at one year to monitor for respiratory symptoms and to establish employees' baseline in lung function and any abnormal decline in lung function in the first year. Subsequently, an annual questionnaire evaluation should occur to monitor for respiratory symptoms. New or worsening respiratory symptoms should prompt additional evaluation including spirometry. Details about spirometry and a medical monitoring program can be found in chapter 9 of the NIOSH Criteria Document [NIOSH 2016].
2. If an employee is identified as likely having lung disease from exposure to diacetyl or 2,3-pentanedione, it should be viewed as a sentinel event indicating a breakdown in exposure controls occurred and potential risk for co-workers exists. Should this occur, the unanticipated source of exposure must be identified and brought under control. In addition, increased intensity of medical surveillance would be required for all employees performing similar job tasks or having similar or greater potential for exposure. The NIOSH Criteria Document provides detailed guidance on responses to such sentinel events [NIOSH 2016].

Smoking Cessation Program

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

Appendix A: Tables

Table A1. Time-weighted average OSHA Method 1013/1016 personal and area air sampling results by location, NIOSH survey, June 2016

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Office Area	1	1 (100%)	2.8	2.8	0
Diacetyl	Personal	Production Area	7	7 (100%)	4.2	18.8	6
Diacetyl	Personal	Roasting	2	2 (100%)	5.0	10.6	1*
Diacetyl	Area	Breakroom	1	1 (100%)	4.9	4.9	N/A
Diacetyl	Area	Café	4	4 (100%)	1.0	2.7	N/A
Diacetyl	Area	Grinding	2	2 (100%)	8.1	9.6	N/A
Diacetyl	Area	Office Area	1	1 (100%)	1.5	1.5	N/A
Diacetyl	Area	Packaging/Storage	4	4 (100%)	6.2	15.0	N/A
Diacetyl	Area	Auto-fill Packaging Machine	2	2 (100%)	8.1	15.2	N/A
Diacetyl	Area	Production Area, Green Bean Silo	2	2 (100%)	5.8	10.8	N/A
Diacetyl	Area	Roasting	2	2 (100%)	5.1	11.8	N/A
2,3-Pentanedione	Personal	Office Area	1	1 (100%)	2.9	2.9	0
2,3-Pentanedione	Personal	Production Area	7	7 (100%)	3.9	18.7	5
2,3-Pentanedione	Personal	Roasting	2	1 (100%)	4.3	10.1	1
2,3-Pentanedione	Area	Breakroom	1	1 (100%)	4.6	4.6	N/A
2,3-Pentanedione	Area	Café	4	4 (100%)	1.6	2.8	N/A
2,3-Pentanedione	Area	Grinding	2	2 (100%)	7.9	9.3	N/A
2,3-Pentanedione	Area	Office Area	1	1 (100%)	1.6	1.6	N/A
2,3-Pentanedione	Area	Packaging/Storage	4	6 (100%)	5.8	14.7	N/A
2,3-Pentanedione	Area	Auto-fill Packaging Machine	2	2 (100%)	7.5	15.2	N/A

Table A1 (cont.). Time-weighted average OSHA Method 1013/1016 personal and area air sampling results by location, NIOSH survey, June 2016

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
2,3-Pentanedione	Area	Production Area, Green Bean Silo	2	2 (100%)	5.1	10.6	N/A
2,3-Pentanedione	Area	Roasting	2	2 (100%)	4.8	11.2	N/A
2,3-Hexanedione	Personal	Office Area	1	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Personal	Production Area	7	1 (13%)	<0.2	0.5	N/A
2,3-Hexanedione	Personal	Roasting	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Personal	Roasting	6	2 (33%)	<0.2	0.4	N/A
2,3-Hexanedione	Area	Breakroom	1	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Cafe	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Grinding	2	2 (100%)	0.5	0.5	N/A
2,3-Hexanedione	Area	Office Area	1	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Packaging/Storage	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Auto-fill Packaging Machine	2	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Production Area, Green Bean Silo	2	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Roasting	2	0 (0%)	<0.4	<0.5	N/A

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD(%)=number and percentage of samples above limit of detection (LOD); < indicates below the limit of detection; ≤ indicated less than or equal to the limit of detection; Above REL=number of samples above the NIOSH recommended exposure limit (REL); ppb=parts per billion; "N/A" NIOSH RELs are specified for personal air samples and area air samples cannot be used for comparison; "Production Area" location includes employees cross-trained and performed tasks at different areas to include the green bean storage, packaging, and grinding areas. "−"indicates that there is currently no REL for 2,3-hexanedione.

***We note that one of the samples collected on a roaster had a TWA of 4.99 ppb and the NIOSH REL is 5 ppb. Although this sample was not above the NIOSH REL, it approached the NIOSH REL.**

Table A2. Summary of OSHA Method 1013/1016 personal air sampling results by task, NIOSH survey, June 2016

Analyte	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (range) Sample Duration (minutes)
Diacetyl	Grind coffee beans	8	8 (100%)	29.8	68.9	13 (2–18)
Diacetyl	Package coffee	8	8 (100%)	5.8	18.0	13 (5–18)
Diacetyl	Roast coffee beans	9	9 (100%)	2.2	9.5	18 (13–22)
2,3-Pentanedione	Grind coffee beans	8	8 (100%)	29.6	84.0	13 (2–18)
2,3-Pentanedione	Package coffee	8	8 (100%)	6.7	15.7	13 (5–18)
2,3-Pentanedione	Roast coffee beans	9	9 (100%)	2.6	10.1	18 (13–22)
2,3-Hexanedione	Grind coffee beans	8	1 (13%)	<0.6	1.5	13 (2–18)
2,3-Hexanedione	Package coffee	8	0 (0%)	<0.6	<2.1	13 (5–18)
2,3-Hexanedione	Roast coffee beans	9	0 (0%)	<0.5	<0.8	18 (13–22)

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; ppb=parts per billion.

Table A3. Instantaneous evacuated canister method* air sampling results by task, NIOSH survey, June 2016

Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Dumping beans from cooling bin into plastic bin	11.7	9.0	1.4
Dumping beans from cooling bin into plastic bin	22.6	15.8	1.6
Dumping beans from cooling bin into plastic bin	8.2	5.5	<1.0
Dumping beans from cooling bin into plastic bin	8.0	6.6	1.1
During auto-fill from auto-fill machine (packaging)	16.9	14.1	2.5
During auto-fill from auto-fill machine (packaging)	17.1	15.0	3.1
During auto-fill near roaster (packaging)	21.5	22.1	1.8
Grinding 12 oz bag; dark roast	30.8	28.6	2.9
Grinding 5-pound bag; dark roast	36.7	35.6	2.0
Grinding 5-pound bag; dark roast	50.4	46.6	4.8
Hand blending 6 lbs of roasted coffee	30.4	26.2	1.4
Pulling sample of roasted beans from roaster to check quality of beans	21.4	17.7	2.3
Pulling sample of roasted beans from roaster to check quality of beans	14.1	10.6	<1.8
Pulling sample of roasted beans from roaster to check quality of beans	11.8	10.3	<1.6
Pulling sample of roasted beans from roaster to check quality of beans	11.5	11.5	<16.4
Vacuuming chaff from roaster exhaust	13.3	11.8	<0.9
Vacuuming chaff from roaster exhaust	14.5	13.6	1.4
Vacuuming chaff from roaster exhaust	14.0	12.8	1.1

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

Table A4. Instantaneous evacuated canister method* air sampling results by source, NIOSH survey, June 2016

Source Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
At transfer point of auto-fill into 12 oz bags; packaging medium/dark roast	5.6	4.8	<1.3
At transfer point of auto-fill into 12 oz bags; packaging medium/dark roast	9.1	7.0	<1.1
At transfer point of auto-fill into 5-pound bags	5.5	4.5	<1.1

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection.
***Sampling duration approximately 30 seconds; source air samples were collected by placing the inlet of the canister sampler near roasted beans.**

Table A5. Headspace analysis results* for bulk samples of roasted coffee beans, NIOSH survey, June 2016

Sample Type	Bulk Sample Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Coffee beans	Medium-dark blend	2,402	2,627	<310
Coffee beans	Decaffeinated roast	3,434	4,145	<310
Coffee beans	Light-medium roast	2,174	2,458	<316
Coffee beans	Light-medium blend	1,515	1,678	<310
Coffee beans	Dark roast	1,983	1,928	<314

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

Table A6. Summary of continuous area air monitoring results for carbon dioxide, carbon monoxide, temperature, relative humidity, and total volatile organic compounds, NIOSH industrial hygiene survey, June 2016

Location	CO_2 (ppm)*	CO (ppm)*	Temperature (°F)*	Relative humidity (%)*	Total VOC (ppb)*
Grinder, day 1	583 (194–1259)	2.8 (0.1–90.2)	74.2 (22.2–76.4)	50.3 (14.3–65.9)	585 (80–13,012)
Roaster, day 1	620 (378–957)	1.9 (0.6–4.2)	80.8 (45.1–86.5)	39.5 (26.5–62.2)	–
Grinder, day 2	548 (511–694)	1.76 (<0.1–74.4)	72.5 (70.8–74.4)	44 (40.0–50.0)	382 (31–2882)
Roaster, day 2	550 (295–687)	1.5 (<0.1–2.5)	80.0 (40.4–96.3)	33.3 (14.1–50.1)	–

Note: NIOSH=National Institute for Occupational Safety and Health; CO_2=carbon dioxide; CO=carbon monoxide; ppm=parts per million; °F=degrees Fahrenheit; VOC=volatile organic compounds; "-"indicates the measurement was not recorded.
***Mean concentration shown with range of measurements shared in the parentheses.**

Table A7. Summary of continuous personal air measurements for carbon monoxide, NIOSH industrial hygiene survey, June 2016

Job Title	Work Area	CO (ppm)*
Roaster	Roaster	2.1 (0–13)
Roaster	Roaster	2.1 (0–5)
Roaster	Roaster	0.8 (0–19)
Production	Production	3.7 (0–63)
Production	Production	3.0 (0–31)
Production Manager	Production and Administrative	3 (0–26)
Production Delivery	Production	2.8 (0–24)
Production Delivery	Production	0.3 (0–24)

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

Table A8. Prevalence of reported symptoms, NIOSH medical survey, June 2016

Symptom	Experienced in the last 12 months N = 15 Number (%)	Experienced in the last 4 weeks N = 15 Number (%)
Nose symptoms*	12 (80%)	5 (33%)
Eye symptoms†	7 (47%)	5 (33%)
Sinusitis or sinus problems	3 (20%)	0 (0%)
Problem with ability to smell	1 (7%)	—
Phlegm on most days for 3 months	1 (7%)	—
Lower respiratory symptoms (reported at least one of the following)	5 (33%)	1 (7%)
Chest wheezing or whistling	5 (33%)	0 (0%)
SOB on level ground or walking up a slight a hill	0 (0%)	—
Breathing trouble	2 (13%)	0 (0%)
Awoke with chest tightness	1 (7%)	0 (0%)
Awoke with shortness of breath	1 (7%)	0 (0%)
Usual cough	1 (7%)	1 (7%)
Asthma attack	1 (7%)	0 (0%)
Systemic symptoms (reported at least one of the following)	7 (47%)	2 (13%)
Flu-like achiness or achy joints	7 (47%)	2 (29%)
Fever or chills	3 (20%)	0 (0%)
Unusual tiredness or fatigue	2 (13%)	0 (0%)

Note: N=number of participants; SOB=shortness of breath; "-"=no four week question was asked for the symptom.
***Nose symptoms includes one or both of the following: 1) stuffy, itchy, or runny nose or 2) stinging, burning nose.**
†Eye symptoms includes one or both of the following: 1) watery, itchy eyes or 2) stinging, burning eyes.

Table A9. Adjusted* comparisons of symptoms and self-reported physician diagnosis among NIOSH medical survey participants with U.S. adult population (N=15) June 2016

Health condition	Comparative population†	Observed Number	Expected Number	SMR (95% CI) ‡
Watery, itchy eyes last 12 months	NHANES III	7	6.6	1.1 (0.5–2.2)
Stuffy, itchy, or runny nose last 12 months	NHANES III	12	9.4	1.3 (0.7–2.2)
Sinus problems last 12 months	NHANES III	3	6.0	0.5 (0.2–1.5)
Phlegm 3 consecutive month or more	NHANES III	1	0.9	1.0 (0.2–6.0)
Wheeze last 12 months	NHANES 2007-2012	5	2.1	2.4 (1.0–5.6)
Ever asthma (physician-diagnosed)	NHANES 2007-2012	1	2.6	0.4 (0.1–2.2)
Current asthma (physician-diagnosed)	NHANES 2007-2012	1	1.3	0.8 (0.1–4.3)

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

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